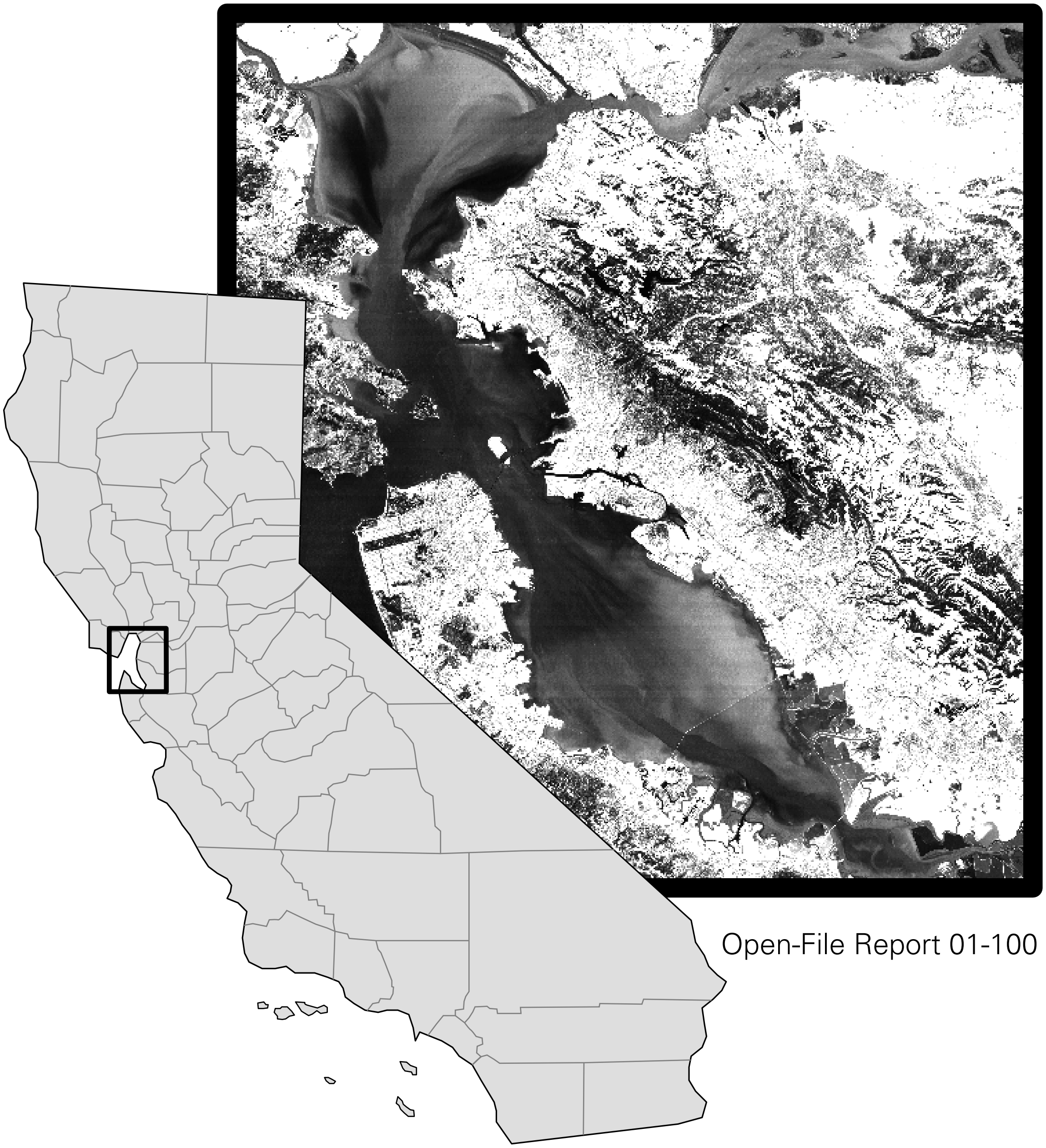
U.S. Department of the Interior
U.S. Geological Survey

Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water Year 1999



Open-File Report 01-100

Prepared in cooperation with the CALFED BAY-DELTA PROGRAM, the
SAN FRANCISCO REGIONAL WATER QUALITY CONTROL BOARD, and the
U.S. ARMY CORPS OF ENGINEERS, San Francisco District

USGS
science for a changing world

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2001**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water year 1999**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Department of the Interior 1849 C Street, NW Washington, DC 20240**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**57**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water Year 1999

By Paul A. Buchanan *and* Catherine A. Ruhl

U.S. GEOLOGICAL SURVEY

Open-File Report 01-100

Prepared in cooperation with the

CALFED BAY-DELTA PROGRAM, the

SAN FRANCISCO REGIONAL WATER QUALITY CONTROL BOARD, and the

U.S. ARMY CORPS OF ENGINEERS, SAN FRANCISCO DISTRICT

3009-36

Sacramento, California
2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

District Chief
U.S. Geological Survey
Placer Hall, Suite 2012
6000 J Street
Sacramento, CA 95819-6129

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	.3048	meter
foot per second (ft/s)	.3048	meter per second
mile (mi)	1.609	kilometer
pound (lb)	.4536	kilogram

Temperature in degrees Celsius (˚C) may be converted to degrees Fahrenheit (˚F) as follows:
˚F = 1.8 (˚C) + 32.

Vertical Datum

***Sea level*:** In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Mean lower low water (MLLW): The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. The National Tidal Datum Epoch is the specific 19-year period (1960-1978 for values given in this report) adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values.

Abbreviations

Ah ampere hour
mg/L milligram per liter
mV millivolt
V volt

Acronyms

AC ....alternating current
ADAPS.....automated data-processing system
DC ....direct current
DWR.........California Department of Water Resources
NTU..........Nephelometric Turbidity Units
PI_{np}...........non-parametric prediction interval
PVC..........polyvinyl chloride
RMS ....root mean squared
USCG.......U.S. Coast Guard
USGS........U.S. Geological Survey

Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water Year 1999

By Paul A. Buchanan *and* Catherine A. Ruhl

ABSTRACT

Suspended-sediment concentration data were collected in San Francisco Bay during water year 1999 (October 1, 1998–September 30, 1999). Optical backscatterance sensors and water samples were used to monitor suspended sediment at one site in Suisun Bay, three sites in San Pablo Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay. Sensors were positioned at two depths at most sites. Water samples were collected periodically and were analyzed for concentrations of suspended sediment. The results of the analyses were used to calibrate the electrical output of the optical backscatterance sensors. This report presents the data-collection methods used and summarizes the suspended-sediment concentration data collected from October 1998 through September 1999. Calibration plots and plots of edited data for each sensor also are presented.

INTRODUCTION

Sediments are an important component of the San Francisco Bay estuarine system. Bottom sediments provide habitat for benthic organisms and are a reservoir of nutrients that contribute to the maintenance of estuarine productivity (Hammond and others, 1985). Potentially toxic substances, such as metals and pesticides, adsorb to sediment particles (Kuwabara and others, 1989; Domagalski and Kuivila, 1993; Flegal and others, 1996). Benthic organisms can ingest these substances and introduce them into the food web (Luoma and others, 1985; Brown and Luoma, 1995; Luoma, 1996).

The transport and fate of suspended sediments are important factors in determining the transport and fate of constituents adsorbed on the sediments. In Suisun Bay, the maximum concentration of suspended sediment usually marks the position of the turbidity maximum, which is a crucial ecological region in which suspended sediments, nutrients, phytoplankton, zooplankton, larvae, and juvenile fish accumulate (Peterson and others, 1975; Arthur and Ball, 1979; Kimmerer, 1992; Jassby and Powell, 1994; Schoellhamer and Burau, 1998).

Suspended sediments limit the availability of light in San Francisco Bay, which, in turn, limits photosynthesis and primary phytosynthetic carbon production (Cole and Cloern, 1987; Cloern, 1987, 1996). Suspended sediments also deposit in ports and shipping channels, which then must be dredged to maintain navigation (U.S. Environmental Protection Agency, 1992). Large tidal velocities, spring tides, and wind waves in shallow water all are capable of resuspending bottom sediments (Powell and others, 1989; Schoellhamer, 1996). The U.S. Geological Survey (USGS), in cooperation with the CALFED Bay-Delta Program, the San Francisco Regional Water Quality Control Board, and the U.S. Army Corps of Engineers, San Francisco District, is studying the factors that affect suspended-sediment concentrations in San Francisco Bay.

Purpose and Scope

This report summarizes suspended-sediment concentration data collected by the USGS in San Francisco Bay during water year 1999 (October 1, 1998–September 30, 1999) and is the latest in a series based on data collected beginning in water year 1992 (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others; 1996; Buchanan and Ruhl, 2000). Suspended-sediment concentrations were monitored at one site in Suisun Bay, three sites in San Pablo Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay. These data are used to determine the factors that affect suspended-sediment concentrations in San Francisco Bay (U.S. Geological Survey, accessed January 19, 2001). Suspended-sediment concentration data for water years 1992 through 1999 are available from the files of the USGS California District Office in Sacramento, California.

Study Area

San Francisco Bay (fig. 1) comprises several major subembayments; Suisun Bay, San Pablo Bay, Central San Francisco Bay (Central Bay), and South San Francisco Bay (South Bay). In San Francisco Bay, tides are semidiurnal (two high and two low tides per day) with a range of about 5.5 feet (ft) in Suisun Bay, 6.5 ft at the Golden Gate and Central Bay, and about 10 ft in South Bay. The tides also have a 14-day spring-neap cycle. Typical tidal currents range from 0.6 feet per second (ft/s) in shallow water to more than 3 ft/s in deep channels (Smith, 1987; Cheng and Gartner, 1984). Winds typically are strongest in summer during afternoon onshore, coastal sea breeze. Most precipitation occurs from late autumn to early spring, and freshwater discharge into the Bay is greatest in the spring due to runoff from snowmelt. About 90 percent of the discharge into the Bay is from the Sacramento–San Joaquin River Delta, which drains the Central Valley of California (Smith, 1987).

Typically, discharge from the Delta contains 83–86 percent of the fluvial sediments that enter the Bay (Porterfield, 1980). During wet winters, turbid plumes of water from the Delta have extended into South Bay (Carlson and McCulloch, 1974). The bottom sediments in South Bay and in the shallow water (about 12 ft or less) of Central, San Pablo, and Suisun Bays are composed mostly of silts and clays. Silts and sands are present in the deeper parts of Central, San Pablo, and Suisun Bays and in Carquinez Strait (Conomos and Peterson, 1977).

Acknowledgments

The authors gratefully acknowledge the U.S. Coast Guard (USCG), California Department of Transportation, California Department of Water Resources (DWR), the San Francisco Port Authority, the PakTank Corporation, and the City of Vallejo for their permission and assistance in establishing the monitoring sites used in this study.

METHODS

Instrument Description and Operation

Three different types of optical backscatterance sensors were used to monitor concentrations of suspended sediment during water year 1999. The first type of sensor is manufactured by D & A Instrument Company and is a cylinder approximately 7 inches (in.) long and 1 in. in diameter with an optical

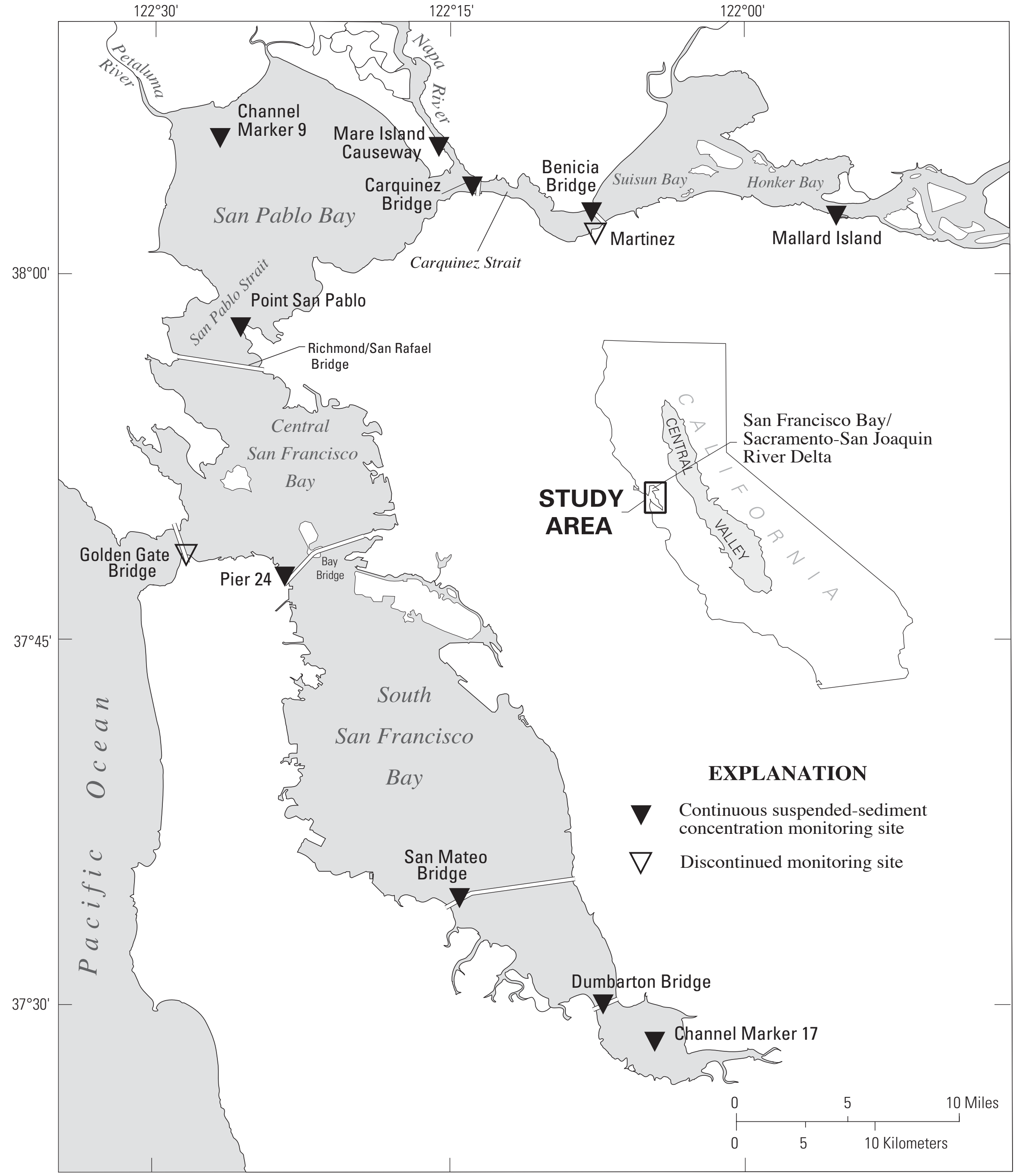


Figure 1. San Francisco Bay study area, California.

window at one end, a cable connection at the other end, and an encased circuit board (Downing and others, 1981; Downing, 1983). A high-intensity infrared emitting diode produces a beam through the optical window that is scattered, or reflected, by particles that are about 0.2–12 in. in front of the window. A detector (four photodiodes) receives backscatter from a field of 140–165° (D & A Instrument Company, 1991) which is converted to a voltage output and recorded on a separate data logger. The second type of sensor, manufactured by BTG, is self-cleaning and similar in size and function to the other optical sensors used in the study, but each self-cleaning probe has a separate electronic unit that sets the resolution and maximum reading, expressed in Nephelometric Turbidity Units (NTU). The voltage output from the electronic unit is recorded on a separate data logger. The third type of sensor, manufactured by Hydrolab, is part of a multiprobe that also measures specific conductance, temperature, and depth. The Hydrolab optical backscatterance sensor measures the intensity of light scattered at 90° from two light-emitting diodes and is expressed in NTU. The multiprobe (or sonde) is self contained with its own power source and data logger. The voltage output for all three types of sensors is proportional to the concentration of suspended sediment in the water column at the depth of the sensor. Suspended-sediment concentrations calculated from the output of side-by-side sensors with and without the self-cleaning function (BTG and D&A Instrument Company), are virtually identical (Buchanan and Schoellhamer, 1998, fig. 4). Calibration of the sensor voltage output to concentrations of suspended sediment will vary according to the size and optical properties of the suspended sediment; therefore, the sensors must be calibrated using suspended material from the field (Levesque and Schoellhamer, 1995).

Optical sensors were positioned in the water column using polyvinyl chloride (PVC) pipe carriages coated with an antifoulant paint to impede biological growth. Carriages were designed to align with the direction of flow and to ride along a stainless steel or Kevlar-reinforced nylon suspension line attached to an anchor weight, which allowed sensors to be easily raised and lowered for servicing (fig. 2). The plane of the optical window maintained its position parallel to the direction of flow as the carriage and sensor aligned itself with the changing direction of flow.

Data acquisition, data storage, and sensor timing were controlled by an electronic data logger. The logger was programmed to power the optical sensor every 15 minutes, collect data each second for 1 minute, then average and store the output voltage for that 1-minute period. Power was supplied by 12-volt (V) direct current (DC), 12-ampere hour (Ah), gel-cell batteries, except for the sonde, which used eight size-C alkaline batteries.

Self-cleaning optical sensors with wipers were deployed at four sites during water year 1994 to reduce biological growth, which interferes with the collection of accurate optical backscatterance data. Because the self-cleaning sensor requires 95–130-V alternating current (AC), installation was limited to sites with AC power. The self-cleaning probes and electronic units were installed at two sites in Suisun Bay and at two sites in South Bay. Fouling in Suisun Bay was minor compared with that in South and Central Bays, and the self-cleaning probes were effective in keeping the optical ports clean. However, fouling at the two sites in South Bay during summer was so extreme that the self-cleaning probes often were rendered ineffective by biological growth on the carriage and wiper mechanism. During water year 1995, all self-cleaning probes deployed in South Bay failed due to salt crystals forming on an O-ring, which resulted in water leakage. To address the leakage problem, the design was modified by the manufacturer. In water year 1996, an updated version of the self-cleaning probe was deployed at the Dumbarton Bridge site in South Bay, but it failed within the first month of operation. Thereafter, the self-cleaning probes were used only at the less saline Mallard Island site in Suisun Bay.

Fouling generally was greatest on the sensor closest to the water surface. However, fouling at shallower sites was similar on both sensors where the upper sensor was set 10 ft above the lower sensor. Optical sensors required frequent cleaning but, due to the difficulty in servicing some of the monitoring stations, they were cleaned every 1-5 (usually 3) weeks. Fouling would begin to affect sensor output from 2 days to several weeks after cleaning, depending on the level of biological activity in the Bay. Generally, biological fouling was greatest during spring and summer.

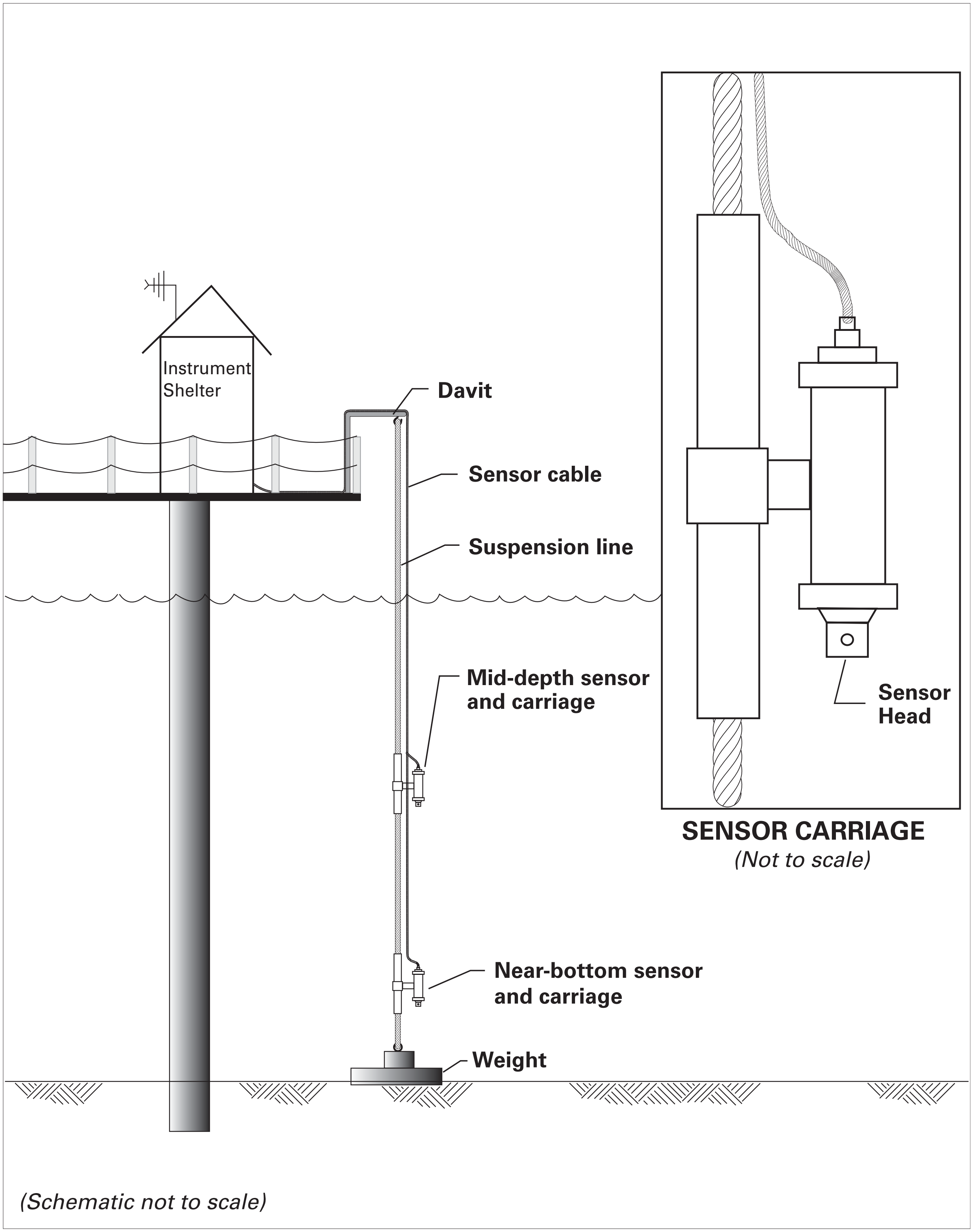


Figure 2. Monitoring installation.

On-site checks of sensor accuracy were performed using turbidity solutions prepared from a 4,000-NTU formazin standard. Formazin is an aqueous suspension of an insoluble polymer and is specified as the primary turbidity standard by the United States Environmental Protection Agency (1992). The turbidity solutions are prepared by diluting a 4,000-NTU stock standard with high-purity water in a clean, sealable bucket. Prepared solutions ranged from 50 to 200 NTU. At the field site, the cleaned sensors are immersed in the solution and the voltage output is recorded on the station log. Monitoring a period of sensor performance in a known standard aids in identifying output drift or sensor malfunction.

Suisun Bay Installations

Suspended-sediment concentration data were collected at Mallard Island in Suisun Bay (fig. 1). A monitoring site at Carquinez Strait at Benicia Bridge was shut down in August 1998 for seismic retrofitting of the bridge and will be reestablished at a future date. Monitoring equipment was installed at the Mallard Island site during water year 1994, and the Benicia Bridge site was established during water year 1996. The monitoring site at the Martinez Marina fishing pier was discontinued in water year 1996 because data from the Benicia Bridge were considered more representative of suspended-sediment concentration in the Carquinez Strait area of Suisun Bay (Buchanan and Schoellhamer, 1998).

Mallard Island

Self-cleaning optical sensors were installed at the DWR Mallard Island Compliance Monitoring Station on February 8, 1994. This site is about 5 miles (mi) downstream from the confluence of the Sacramento and San Joaquin Rivers and is at the north shore of Mallard Island near the eastern boundary of Honker Bay, a subembayment of Suisun Bay (fig. 1). The station was constructed in the early 1980's by DWR on Pacific Gas and Electric Company property, and water-quality data were first recorded at the station in January 1984. A 1/4-mi wooden walkway crosses the sometimes submerged reedbeds of Mallard Island and connects the concrete-block instrument shelter to the levee road.

Sensors were positioned at near-bottom (5 ft above the bottom) and near-surface (3.3 ft below the surface) depths to coincide with DWR near-bottom depth electrical conductance and temperature sensors and the near-surface pump intake. The pump intake was attached to a float that is housed inside a 12-in. PVC pipe, and the intake drew water from about 3 ft below the surface. Mean lower low water depth at this site was about 25 ft. DWR near-surface parameters were measured by sensors that are submerged in flow-through chambers inside the instrument shelter. This configuration saved the cost of installing duplicate sets of sensors and enabled the USGS to use DWR instruments for data, such as stage, pH, chlorophyll concentration, and meteorological parameters.

Data storage is controlled by a data logger connected to a cellular phone and modem. AC power operated both optical sensors and charged a 12-V, 12-Ah battery that powered the data logger and modem. The data logger and peripheral equipment are housed in the instrument shelter. The sensors were suspended from a galvanized support stand that was attached to a metal railing on the station's northwest concrete deck. The support stand has two stainless-steel lines attached to separate concrete weights; one line for the near-bottom sensor and one line for the near-surface sensor. The near-bottom sensor was attached to a PVC carriage suspended from the stainless-steel line by a nylon rope. The near-surface sensor was attached to a PVC carriage that was built onto a float. This float assembly moved up and down the suspension line during tidal cycles, which maintained the near-surface sensor at the same depth as the DWR pump intake. A pressure transducer was positioned on the float assembly at the same level as the sensor and provided data to verify the depth of the near-surface sensor. To prevent sensor cables from being snagged by debris, a counterweight was installed to keep slack cables out of the water.

San Pablo Bay Installations

Suspended-sediment concentration data were collected at three sites in San Pablo Bay; Carquinez Bridge, Mare Island Causeway, and Channel Marker 9 (fig. 1).

Carquinez Bridge

Suspended-sediment monitoring equipment was installed April 21, 1998, at the Carquinez Bridge. This site is located on the north side of the center pier structure of the Carquinez Bridge (fig. 1). Sondes with optical, specific conductance, temperature, and depth sensors were deployed at near-bottom and mid-depths (5 ft and 48 ft, respectively, from the bottom). Mean lower low water depth at this site was about 88 ft. The sensors were suspended between the concrete pier superstructure and the fender boards, which were approximately 1 ft apart. PVC carriages attached to 1/4-in. stainless-steel line were anchored to a 250-pound (lb) weight and used to suspend the sensors at the desired depth. Sensor timing and data storage were controlled by an internal data logger powered by eight size-C alkaline batteries that were replaced during site visits. No instrument shelter was needed at this site.

Mare Island Causeway

The USGS maintains a monitoring site on the Napa River at Mare Island Causeway near Vallejo (fig. 1). The USGS established this site in cooperation with the California Coastal Conservancy in water year 1998. The USGS assumed full operation of this site in water year 1999.

Optical sensors were installed at Mare Island Causeway on October 1, 1998, and were positioned at near-bottom and mid-depth (5 ft and 15 ft, respectively, from the bottom). Mean lower low water depth at this site was about 30 ft. Specific conductance and temperature data were collected at near-bottom and near-surface points in the water column (near-bottom and near-surface depths were sampled to define the vertical stratification). Sensor timing and data storage were controlled by a data logger. PVC carriages attached to 1/4-in. stainless-steel line were anchored to a 125-lb weight and were used to suspend the sensors at the desired depth. AC power charged a 12-V, 12-Ah battery that powered the data logger and sensors. The data logger and peripheral equipment were housed in a 3 × 2 × 1-ft plastic weather-proof shelter mounted on a catwalk underneath the causeway.

Channel Marker 9

Suspended-sediment monitoring equipment was installed November 12, 1998, at USCG Channel Marker 9. This site was located in the navigation channel leading to the Petaluma River in the northwest corner of San Pablo Bay (fig. 1). A sonde with optical, specific conductance, temperature, and depth sensors was deployed at near-bottom depth (2 ft above the bottom). Mean lower low water depth at this site was about 6 ft. The sensor was suspended from the channel marker platform using a PVC carriage attached to 1/4-in. stainless-steel line anchored to a 125-lb weight. Sensor timing and data storage were controlled by an internal data logger powered by eight size-C alkaline batteries that were replaced during site visits. No instrument shelter was needed at this site.

Central San Francisco Bay Installations

Suspended-sediment concentration data were collected at two sites in Central Bay: Point San Pablo and Pier 24 (fig. 1).

Point San Pablo

The USGS maintains a monitoring site at San Pablo Strait on the northern end of the Richmond Terminal No. 4 pier on the western side of Point San Pablo (fig. 1). The USGS assumed operation of this site from DWR in October 1989. Data collected prior to October 1, 1989, can be obtained from DWR.

Optical sensors were installed at Point San Pablo on December 1, 1992, and were positioned at near-bottom and middle depths (3 ft and 13 ft, respectively, from the bottom). Mean lower low water depth at this site was about 26 ft. Specific conductance and temperature data (cooperatively funded by DWR and the USGS) were collected at near-bottom and near-surface depths in the water column (near-bottom and near-surface depths were sampled to define vertical stratification). Sensor timing and data storage were controlled by a data logger connected to a phone line and modem. PVC carriages attached to 1/4-in. stainless-steel line were anchored to a 125-lb weight and were used to suspend the sensors at the desired depth. Water level was recorded using a float-driven incremental encoder wired into the data logger; outside water levels were read during site visits using a wire-weight gage. AC power charged a 12-V, 60-Ah battery that powered the data logger and sensors. The data logger and peripheral equipment were housed in a 5×8×8-ft wooden shelter.

Pier 24

The monitoring station at Pier 24 is on the western end of the San Francisco–Oakland Bay Bridge (fig. 1). The USGS assumed operation of this station from DWR in October 1989. Data collected prior to October 1, 1989, can be obtained from DWR.

Optical sensors were installed at the Pier 24 site on May 25, 1993, and were positioned at near-bottom and middle depths (3 ft and 23 ft, respectively, from the bottom). Mean lower low water depth at this site was about 41 ft. As at the Point San Pablo station, specific conductance and temperature data (cooperatively funded by DWR and the USGS) were collected at near-bottom and near-surface depths in the water column. PVC carriages attached to 1/4-in. stainless-steel line were anchored to a 125-lb weight and used to suspend the sensors at the desired depth. Sensor timing and data storage were controlled by a data logger connected to a cellular phone and modem. AC power charged two 12-V, 12-Ah batteries that powered the instrumentation. The data logger and peripheral equipment were housed in a corrugated steel shelter.

South San Francisco Bay Installations

Suspended-sediment concentration data were collected at three sites in South Bay (fig. 1). Monitoring sites were installed during water year 1992 at two sites in South Bay; Channel Marker 17 and San Mateo Bridge. The Dumbarton Bridge site was installed during water year 1993.

Channel Marker 17

The southernmost monitoring site in South Bay is at the USCG Channel Marker 17 (fig. 1). Instrumentation was installed on February 26, 1992, and the optical sensors were positioned at near-bottom and middle depths (3 ft and 13 ft, respectively, from the bottom). Mean lower low water depth at this site was about 25 ft. Sensor cables were protected by a 10-ft PVC pipe suspended from the channel marker platform. Sensor timing and data storage were controlled by a data logger. PVC carriages attached to 1/4-in. Kevlar-reinforced nylon line were anchored to a 100-lb weight and used to suspend the sensors at the desired depth. The data logger and 12-V, 12-Ah batteries were housed in a 2 × 2 × 1-ft plastic weather-proof shelter mounted on the channel marker platform.

Dumbarton Bridge

Suspended-sediment concentration monitoring equipment was installed on October 21, 1992, at Pier 23 of the Dumbarton Bridge on the west side of the ship channel (fig. 1). Optical sensors were deployed at near-bottom and middle depth (4 ft and 23 ft, respectively, from the bottom). Mean lower low water depth was about 45 ft. The sensors were suspended between the concrete pier superstructure and its surrounding protective fender boards, a space approximately 3 ft wide. Sensor timing and data storage were controlled by a data logger. PVC carriages attached to 1/4-in. stainless-steel line were anchored to a 125-lb weight and suspended the sensors at the desired depth. AC power charged a 12-V, 12-Ah battery that powered the instrumentation. The data logger and peripheral equipment were housed in a 3×2×1-ft plastic weather-proof shelter mounted on the pier.

San Mateo Bridge

The monitoring site on the San Mateo Bridge is at Pier 20 on the east side of the ship channel (fig. 1). This station was operated by DWR, but the USGS assumed operations in October 1989. Data collected prior to October 1, 1989, can be obtained from DWR.

The optical sensors were installed on December 23, 1991, and were positioned at near-bottom and middle depths (8 ft and 29 ft, respectively, above the bottom). Mean lower low water depth at this site was about 48 ft. The sensors were deployed between the pier and a protective fender structure composed of multiple piles; flow past the sensors was significantly affected by the pilings and the concrete superstructure. PVC carriages attached to 1/4-in. stainless-steel line were anchored to a 200-lb weight and suspended the sensors at the desired depth. Sensor timing and data storage were controlled by a data logger. In addition to suspended-sediment concentrations, specific conductance and temperature (cooperatively funded by DWR and the USGS) were monitored at near-bottom and near-surface depths. AC power charged a 12-V, 60-Ah battery that powered the data logger and sensors. The data logger and peripheral equipment were housed in an 8×6×8-ft wooden shelter on the pier.

Water-Sample Collection

Water samples, used to calibrate optical sensors, were collected using a horizontally positioned Van Dorn sampler before and after the sensors were cleaned. The Van Dorn sampler is a plastic tube with rubber stoppers at each end that snap shut when triggered by a small weight dropped down a suspension cable. The Van Dorn sampler was lowered to the depth of the sensor by a reel and crane assembly and triggered while the sensor was collecting data. Then, the water sample was removed from the sampler, marked for identification, and placed in an ice chest to limit biological growth. The suspended-sediment concentration of water samples collected with a Van Dorn sampler and a P-72 point sampler, used until water year 1994, were compared and found to be virtually identical (Buchanan and others, 1996, fig. 2).

An auto-sampler was used during water year 1999 to help calibrate the near-surface sensor at Mallard Island. The auto-sampler is a programmable peristaltic pump with 1/4-in. plastic tubing capable of collecting 24 separate samples. The auto-sampler tubing was deployed at the depth of the sensor by strapping the tubing to the sensor cables. The auto-sampler was programmed to collect samples hourly while the sensor was collecting data.

Samples were sent to the USGS Sediment Laboratory in Salinas, California, for analysis of suspended-sediment concentration. Suspended sediment include all particles in the sample; the suspended sediment (material that settles to the bottom of the sample bottle) and buoyant particles that do not settle. Suspended-sediment concentration were previously referred to as suspended-solids concentration in previous reports (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others, 1996, Buchanan and Ruhl, 2000). The analytical method used to quantify concentrations of suspended

solid-phase material define the nomenclature used to describe sediment data (Gray and others, 2000). Water samples used in this and preceding reports were analyzed as suspended-sediment concentration (total water-sediment mass and all sediment were measured). Each sample was filtered through a 0.45-micrometer membrane filter, the filter was rinsed to remove salts, and the insoluble material was dried at 103°C and weighed (Fishman and Friedman, 1989).

Data Processing

Data loggers stored the voltage outputs from the optical sensors at 15-minute intervals (96 data points per day). Recorded data were downloaded from the data logger onto a storage module during site visits. Raw data from the storage modules were loaded into the USGS automated data-processing system (ADAPS).

The time-series data were retrieved from ADAPS and edited using MATLAB software to remove invalid data. Invalid data included rapidly increasing voltage outputs and unusually high voltage outputs of short duration. As biological growth accumulated on the optical sensors, the voltage output of the sensors increased (except for the sonde's optical sensor output, which decreased). An example time series of raw and edited optical backscatterance data from water year 1994 is presented in figure 3. After sensors were cleaned, sensor output immediately decreased (fig. 3, April 19, June 8, and June 28). Efforts to correct the invalid data proved to be unsuccessful because the desired signal was sometimes highly

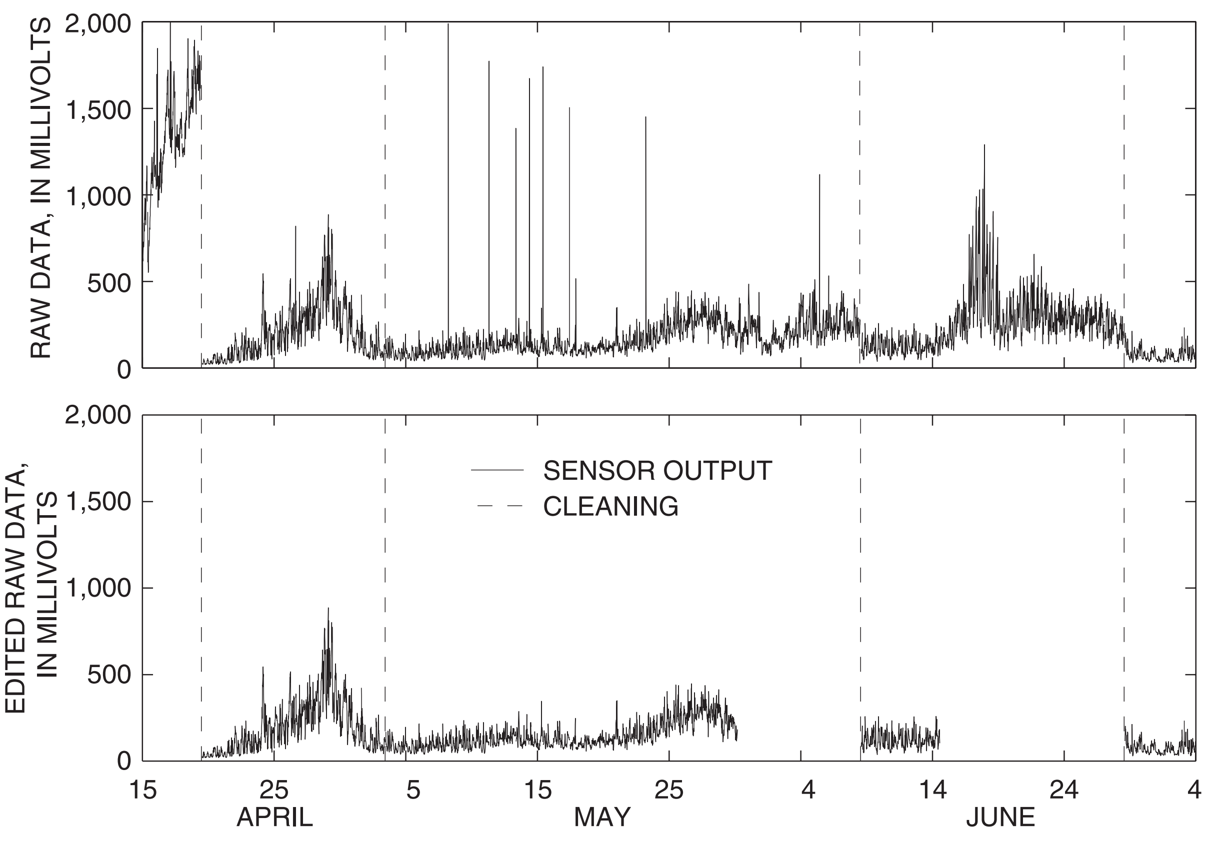


Figure 3. Example of raw and edited optical backscatterance data, mid-depth sensor, Point San Pablo, Central San Francisco Bay, California, water year 1994 (Buchanan and others, 1996).

variable. Thus, data collected during the period prior to sensor cleaning often were unusable and were removed from the record (fig. 3). Spikes in the data, which are anomalously high voltages probably caused by debris temporarily wrapped around the sensor or by large marine organisms (fish, crabs) on or near the sensor, also were removed from the raw data record (fig. 3). Sometimes, incomplete cleaning of a sensor would cause a small, constant shift in sensor output that could be corrected using water-sample data.

SENSOR CALIBRATION AND SUSPENDED-SEDIMENT CONCENTRATION DATA

The output from the optical sensors was converted to suspended-sediment concentration using the robust, non-parametric, repeated median method (Siegel, 1982). In addition, the prediction interval and the 95 percent confidence interval were calculated and presented for each calibration relation.

The repeated median method calculates the slope in a two-part process. First, for each point *(X,Y)*, the median of all possible “point *i*” to “point *j*” slopes was calculated

$$\beta_i = median\frac{(Y_j - Y_i)}{(X_j - X_i)} \qquad \text{for all } j \neq i\,.$$

The calibration slope was calculated as the median of β_i

$$\text{slope} = \hat{\beta}_1 = median(\beta_i)\,.$$

Finally, the calibration intercept was calculated as the median of all possible intercepts using the slope calculated above

$$\text{intercept} = \hat{\beta}_0 = median(Y_i - \hat{\beta}_1 X_i)\,.$$

The final linear calibration equation is

$$Y = \hat{\beta}_1 X + \hat{\beta}_0\,.$$

The non-parametric prediction interval (PI_{np}) (Helsel and Hirsch, 1992, p. 76) is a constant-width error band that contains 68.26 percent, or one standard deviation, of the calibration data set. The 68.26-percent value was selected because it has essentially the same error prediction limits as the root-mean-squared (RMS) error of prediction in ordinary least squared regression: the latter was used in previous data reports (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others, 1996) to analyze random sets of normally distributed data. The prediction interval describes the likelihood that a new observation comes from the same distribution as the previously collected data set.

It is important to note that the PI_{np}, unlike the RMS error of prediction, frequently is not symmetrical about the regression line. For example, the PI_{np} may be reported as +10 milligrams per liter (mg/L) and −7 mg/L. This asymmetry about the regression line is a result of the non-normal distribution of the data set. The PI_{np} is calculated by computing and sorting, from least to greatest, the residuals for each point. Then, based on the sorted list of residuals

$$\text{non-parametric prediction interval} = PI_{np} = \hat{Y}_{\left(\frac{\alpha}{2}\right)(n+1)} \text{ to } \hat{Y}_{\left(1-\frac{\alpha}{2}\right)(n+1)},$$

where

$\hat{Y}$ is the residual value,

n is the number of data points, and

α is the confidence level of 0.6826.

To calculate the confidence interval, all possible point-to-point slopes must be sorted in ascending order. Based on the confidence interval desired, 95 percent for the purposes of this report, the ranks of the upper and lower bounds are calculated as follows:

$$Ru = \left(\frac{\frac{n(n-1)}{2} + 1.96\left(\sqrt{\frac{n(n-1)(2n+5)}{18}}\right)}{2} + 1 \right), \text{ and}$$

$$Rl = \frac{\frac{n(n-1)}{2} - 1.96\left(\sqrt{\frac{n(n-1)(2n+5)}{18}}\right)}{2}$$

where

Ru is the rank of the upper bound slope,

Rl is the rank of the lower bound slope, and

n is the number of samples.

To establish the 95-percent confidence interval, the ranks calculated above are rounded to the nearest integer and the slope associated with each rank in the sorted list is identified. This is a large-sample approximation and was used for each of the confidence intervals presented in this report. However, in the event that fewer than 10 samples had been collected, a direct calculation can be performed based on the methodology presented in Helsel and Hirsh (1992, p. 273–274).

A statistical summary of the calculated suspended-sediment concentrations is presented in table 1. The usable percent of a complete year of data (96 data points per day) collected by optical backscatterance sensors at each site is presented in table 2.

This section of the report also includes the robust regression (calibration) plots for optical sensor output versus suspended-sediment concentration (in milligrams per liter). The repeated median regression plots include the number of water samples, the calculated linear correlation equation, the nonparametric prediction interval (shown on the plots as a grey band), and the 95-percent confidence interval (shown on the plots as a dash-dot line). Finally, the time-series plots of suspended-sediment concentration data are shown for each site.

Suisun Bay

Mallard Island

The calibration of the near-surface, self-cleaning probe (fig. 4*A*) was developed from 102 water samples collected from December 9, 1994, through May 24, 1999; flood samples collected from January through March 1995, January through February 1997, and February through March 1998 were excluded (flood conditions, which can cause a change in sensor calibration, did not occur in water year 1999). The near-surface probe malfunctioned after the site visit on May 24 and was replaced on June 29, 1999. The calibration of the near-surface replacement probe (fig. 4*B*) was developed from 14 water samples collected from June 29, 1999, through February 8, 2000. An auto-sampler was installed on September 23, 1999, at the near-surface position that collected hourly water samples during a 24-hour period. Analysis of the 24 water samples collected by the auto-sampler indicated a shift in the calibration of the near-surface probe, which was not verified by previous or subsequent water samples. All water samples collected by the auto-sampler were eliminated from the analysis due to the inability to ensure that the auto-sampler was not causing a bias to the data. The calibration of the near-bottom self-cleaning probe (fig. 5) was developed from 121 water samples collected from April 20, 1995, through water year 1999; flood samples collected from January through February 1997 and February through March 1998 were excluded. The data collected by the near-bottom probe from June 29 through July 28, 1999, was deleted from the record due to erratic data patterns and inability to correlate the voltages with water-sample data. Suspended-sediment concentration data collected during water year 1999 are presented in figure 6.

Table 1. Statistical summary of suspended-sediment concentration data, Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, California, water year 1999

[All measurements are in milligrams per liter. Lower quartile is 25th percentile; upper quartile is 75th percentile; NA, not applicable]

Site	Latitude	Longitude	Depth	Mean	Median	Lower quartile	Upper quartile
Mallard Island	38°02'34"	121°55'09"	Near-surface	42	39	31	49
			Near-bottom	46	38	23	58
Carquinez Bridge	38°03'41"	122°13'23"	Mid-depth	66	46	22	78
			Near-bottom	203	151	52	297
Mare Island Causeway	38°06'40"	122*16'25"	Mid-depth	80	61	39	101
			Near-bottom	186	144	89	235
Channel Marker 9	38°05'19"	122°26'29"	Near-bottom	213	142	81	263
Point San Pablo	37°57'53"	122°25'42"	Mid-depth	48	40	28	59
			Near-bottom	81	62	40	99
Pier 24	37°47'27"	122°23'05"	Mid-depth	25	22	18	29
			Near-bottom	33	28	22	38
Channel Marker 17	37°28'44"	122°04'38"	Mid-depth	132	96	56	170
			Near-bottom	171	112	64	215
Dumbarton Bridge	37°30'15"	122°07'10"	Mid-depth	95	76	52	117
			Near-bottom	150	127	80	190
San Mateo Bridge	37°35'04"	122°14'59"	Mid-depth	60	47	30	73
			Near-bottom	N/A	N/A	N/A	N/A

Table 2. Usable percentage of a complete year of data (96 data points per day) collected by optical backscatterance sensors, Suisun Bay, San Pablo Bay, Central and South San Francisco Bays, California, water year 1999

Site	Depth	Percent valid data
Mallard Island	Near-surface	81
	Near-bottom	70
Carquinez Bridge	Mid-depth	52
	Near-bottom	41
Mare Island Causeway	Mid-depth	91
	Near-bottom	89
Channel Marker 9	Near-bottom	62
Point San Pablo	Mid-depth	73
	Near-bottom	94
Pier 24	Mid-depth	52
	Near-bottom	56
Channel Marker 17	Mid-depth	74
	Near-bottom	75
Dumbarton Bridge	Mid-depth	55
	Near-bottom	59
San Mateo Bridge	Mid-depth	30
	Near-bottom	0

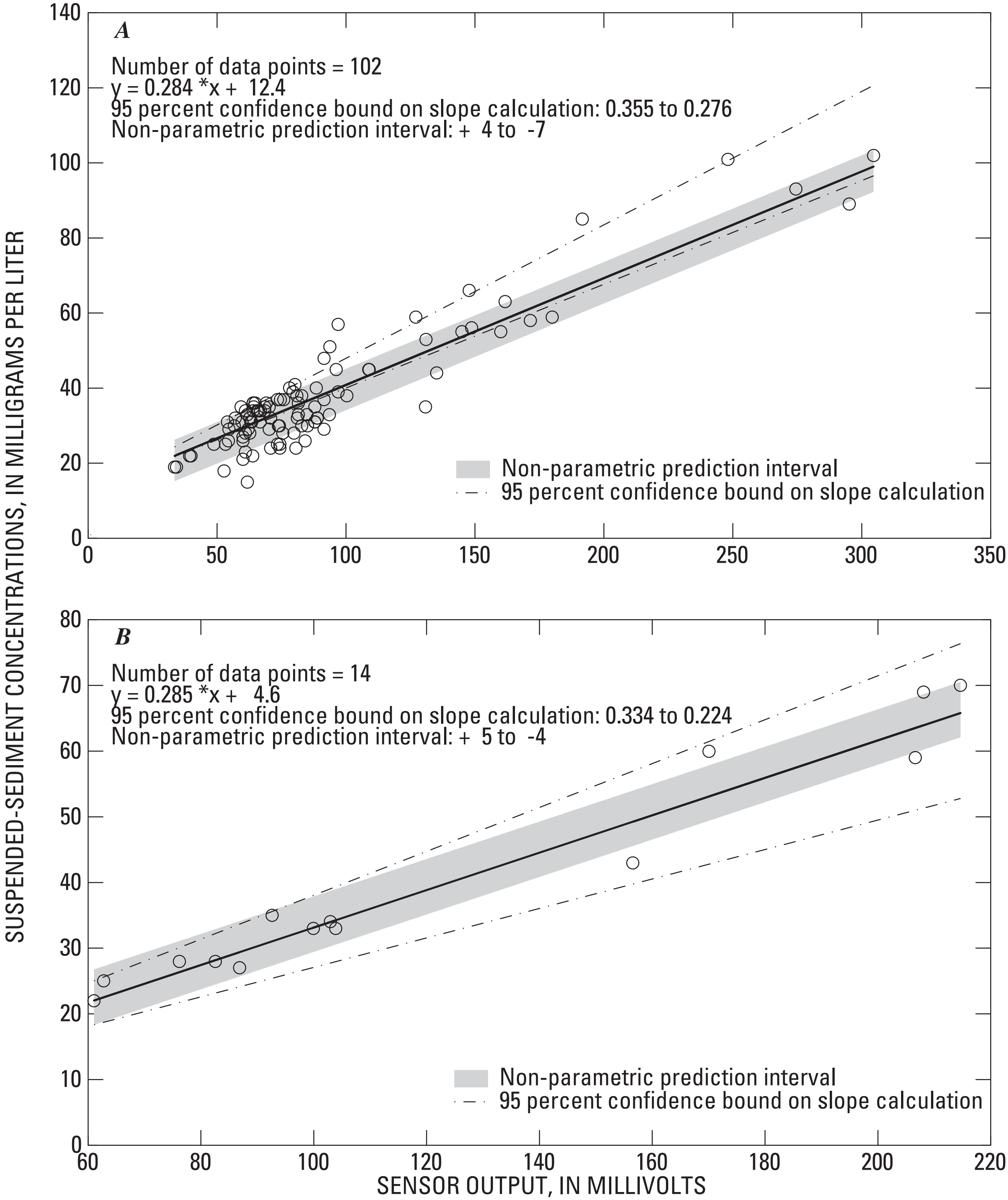


Figure 4. Calibration of near-surface optical backscatterance sensor October 1–May 24 (*A*) and June 29–September 30 (*B*) at Mallard Island, Suisun Bay, California, water year 1999.

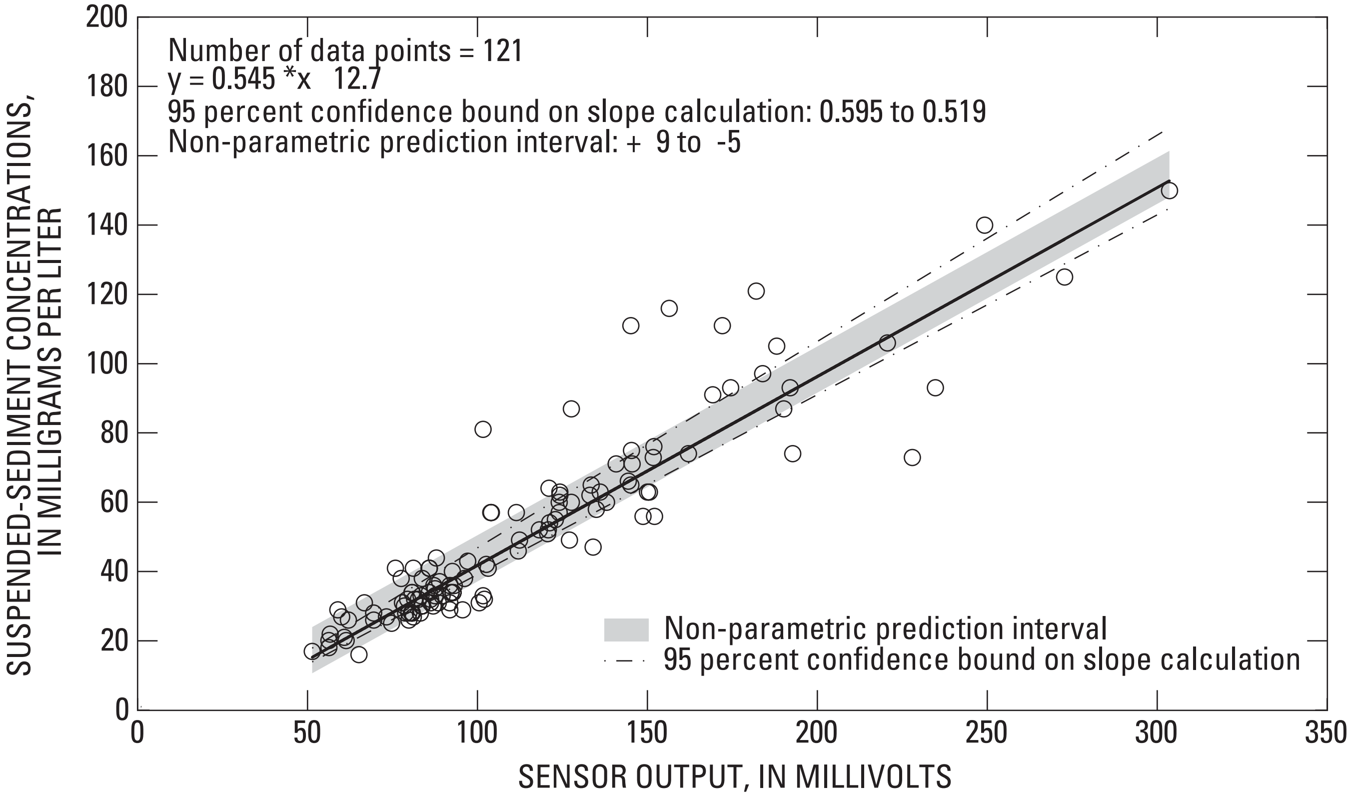


Figure 5. Calibration of near-bottom optical backscatterance sensor at Mallard Island, Suisun Bay, California, water year 1999.

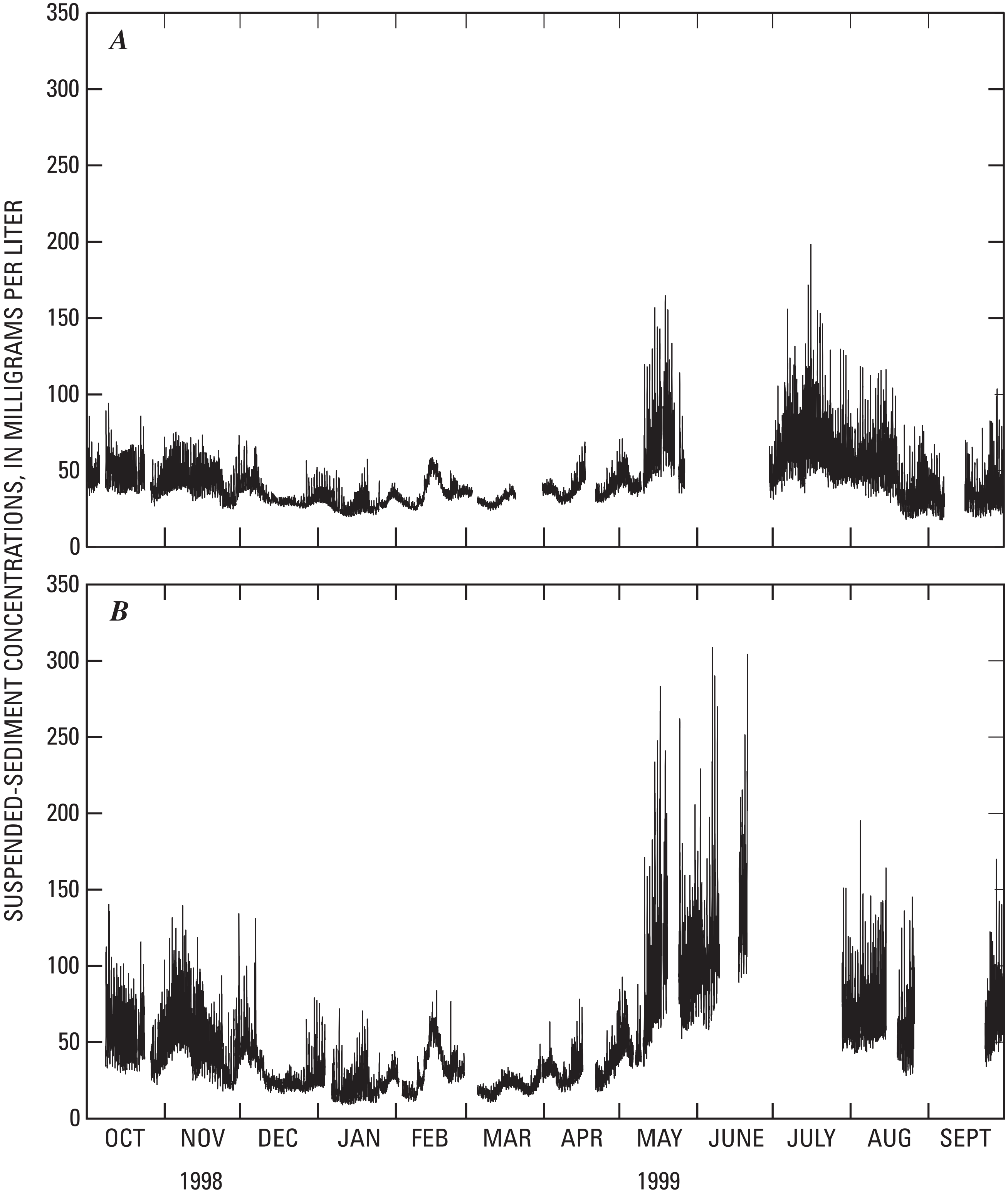


Figure 6. Time series of near-surface (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 1999.

San Pablo Bay

Carquinez Bridge

The suspension line for the sensors was found broken on October 1, 1998, and was replaced on October 15, 1998. A single calibration was used for the mid-depth and near-bottom sensors and was developed from 33 water samples (20 water samples collected from the upper position and 13 collected from the lower position) collected from June 23, 1998, through water year 1999 (fig. 7). Using a single calibration for both sensors was possible because the sensors were factory calibrated using the same NTU standard and were verified by on-site field checks during the period of deployment using NTU standards of varying concentrations. The mid-depth sonde was replaced due to failure of the instrument on April 7, 1999, and June 10, 1999. The near-bottom sonde's data logger did not store data from October 15, 1998, through March 17, 1999. The male pins on the near-bottom sonde's communication port were found to be corroded on September 7, 1999, and the sonde was replaced. The near-bottom data file from August 11 through September 7, 1999, was lost when the unit was sent for repairs. Suspended-sediment concentration data collected during water year 1999 are presented in figure 8.

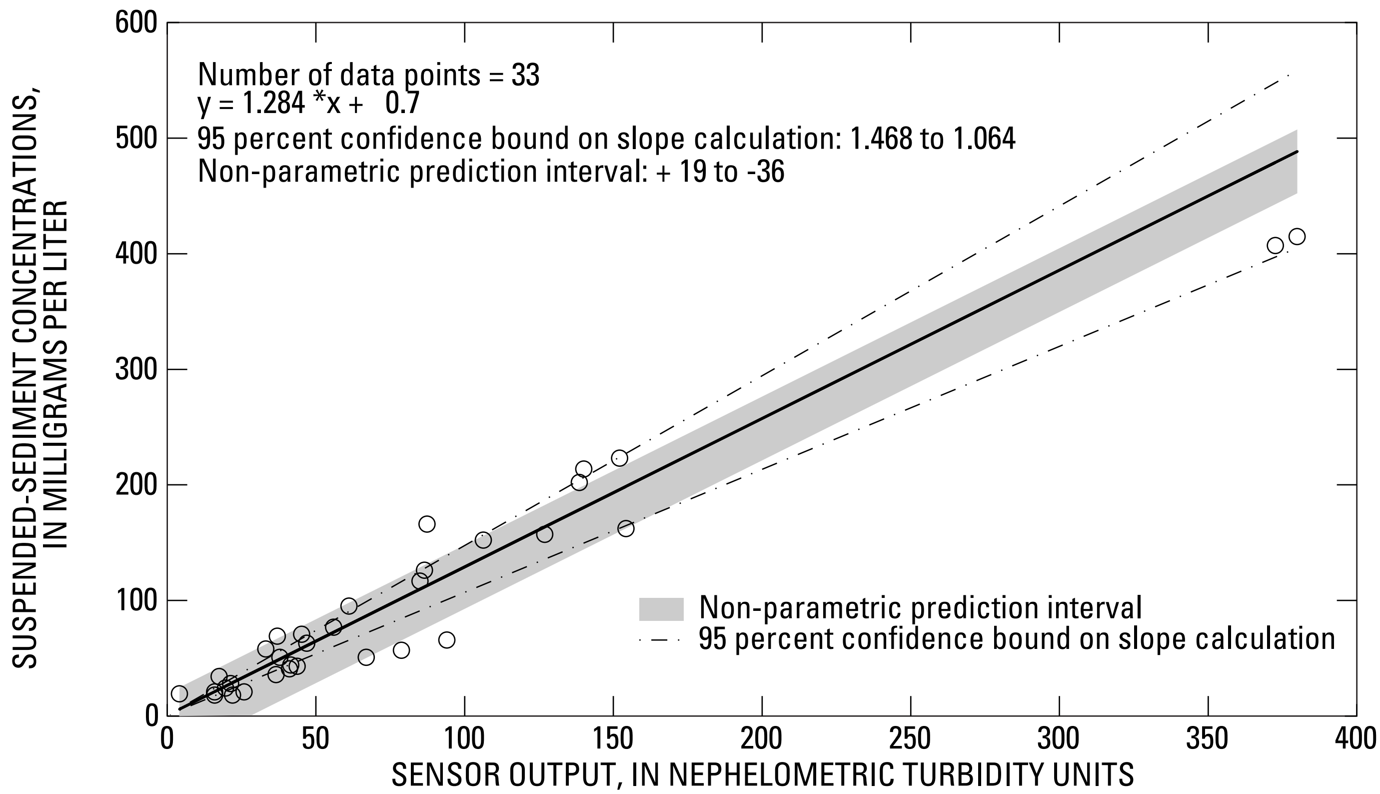


Figure 7. Calibration of mid-depth and near-bottom optical backscatterance sensors at Carquinez Bridge, San Pablo Bay, California, water year 1999.

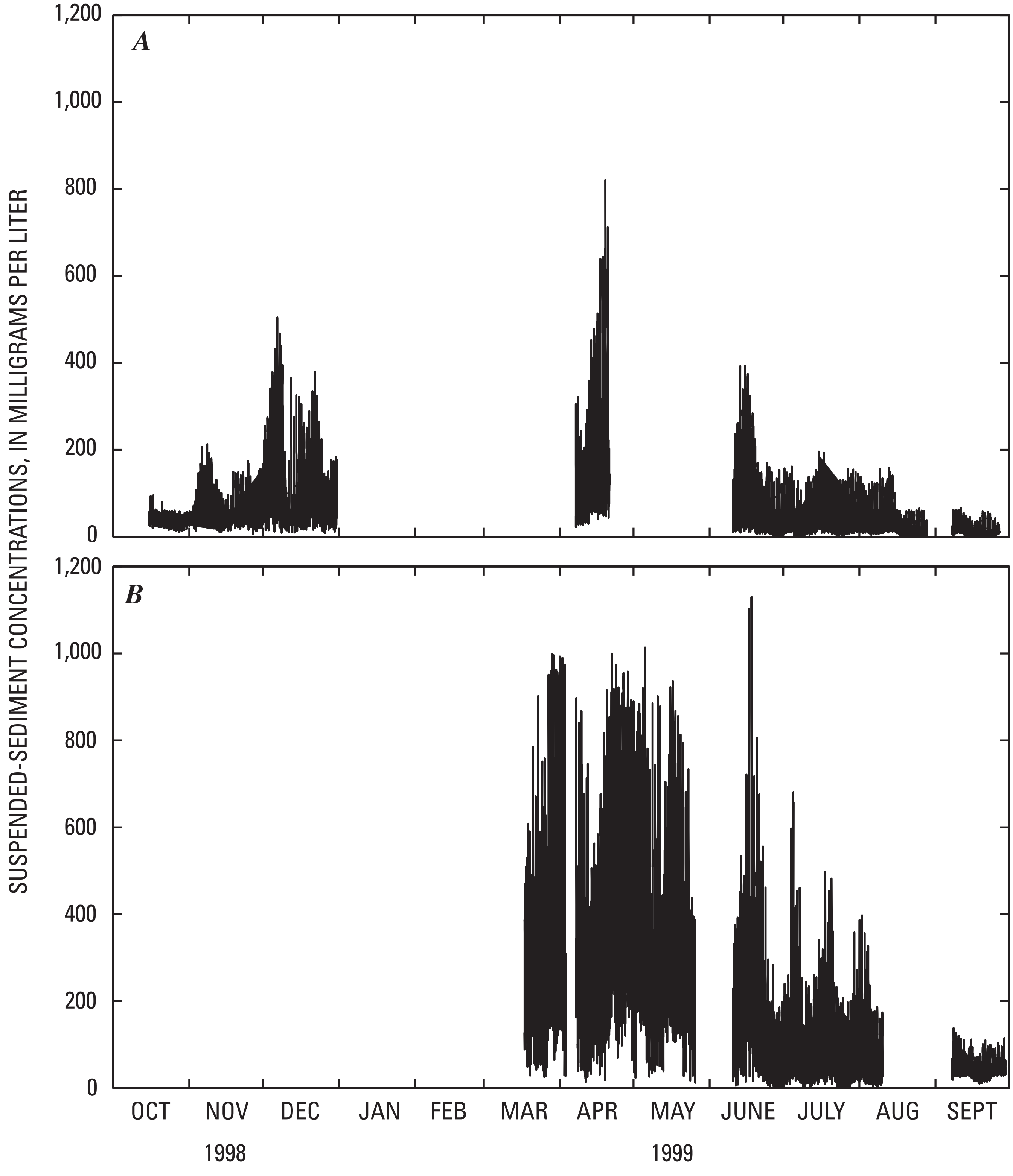


Figure 8. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Carquinez Bridge, San Pablo Bay, California, water year 1999.

Mare Island Causeway

The calibration of the mid-depth sensor was developed from 30 water samples collected from October 6, 1998, through water year 1999 (fig. 9*A*). The calibration of the near-bottom sensor was developed from 30 water samples collected from October 6, 1998, through water year 1999 (fig. 9*B*). The station was shut down from December 29, 1998, through January 4, 1999, when the conductivity and temperature sensors were replaced. Suspended-sediment concentration data collected during water year 1999 are presented in figure 10.

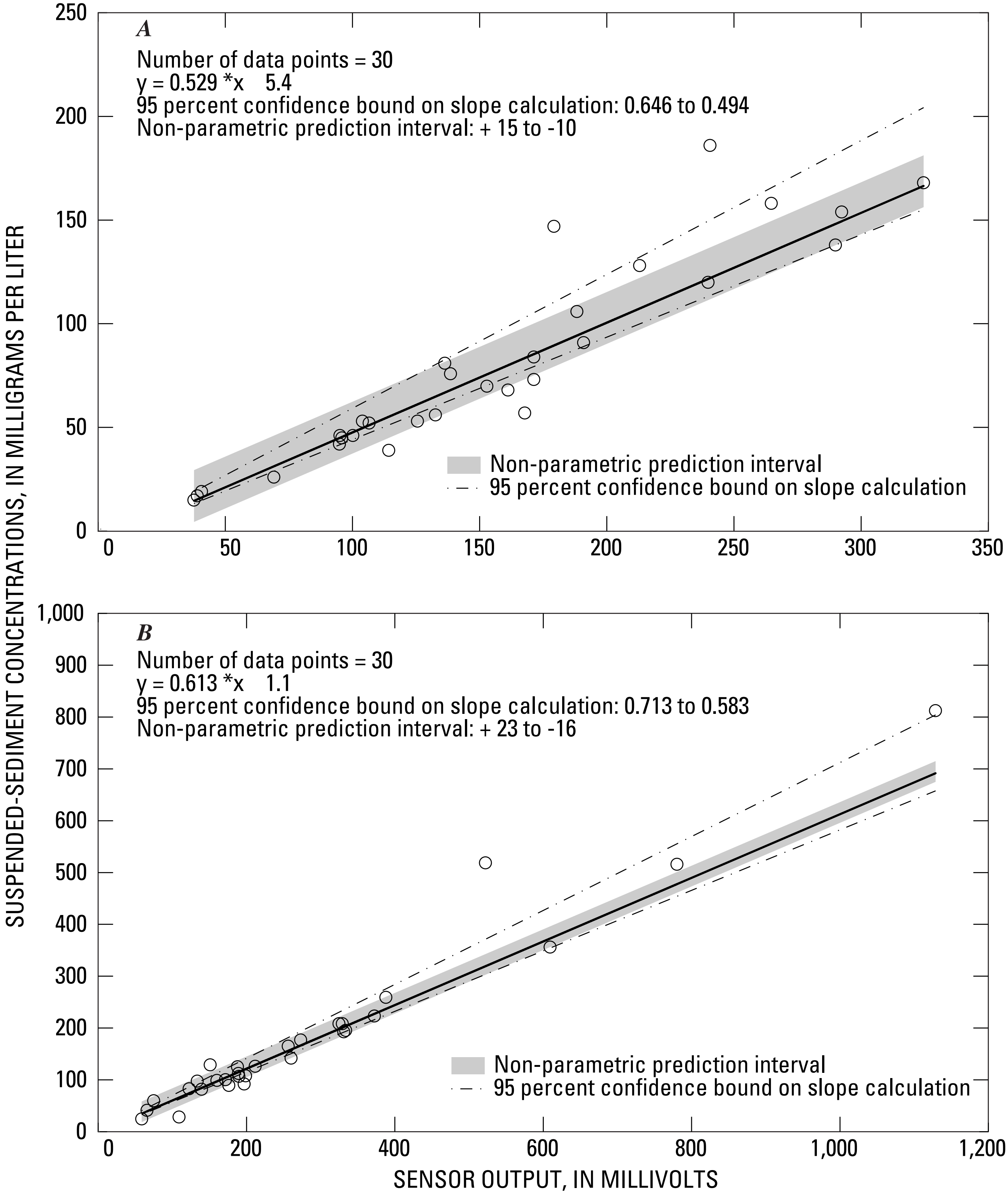


Figure 9. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Mare Island Causeway, San Pablo Bay, California, water year 1999.

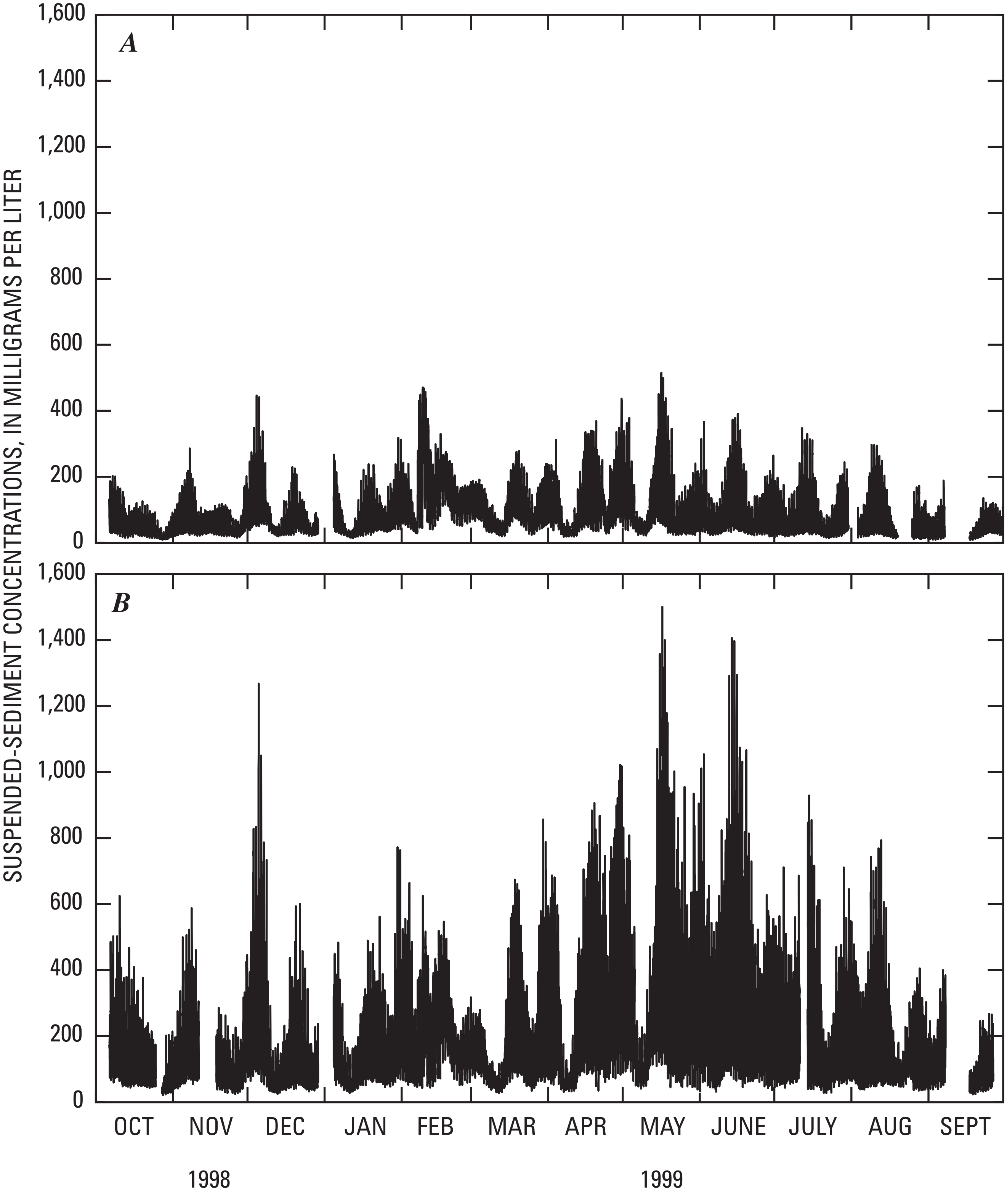


Figure 10. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Mare Island Causeway, San Pablo Bay, California, water year 1999.

Channel Marker 9

A time shift (+9 hours) was applied to the record from November 12, 1998, through June 26, 1999, to correct a time lag in the sonde's internal clock. The 9-hour discrepancy between the sonde's internal clock and Pacific Standard Time (to which the data files were programmed) resulted in all after-cleaning water samples collected during this period to be unusable. The calibration of the near-bottom sensor was developed from 11 water samples collected from November 12, 1998, through water year 1999 (fig. 11*A*). The optical sensor on the sonde can measure a maximum of 1,000 NTU, which was exceeded on February 17 and 18, 1999, at maximum ebb during a strong spring tide. Suspended-sediment concentration data collected during water year 1999 are presented in figure 11*B*.

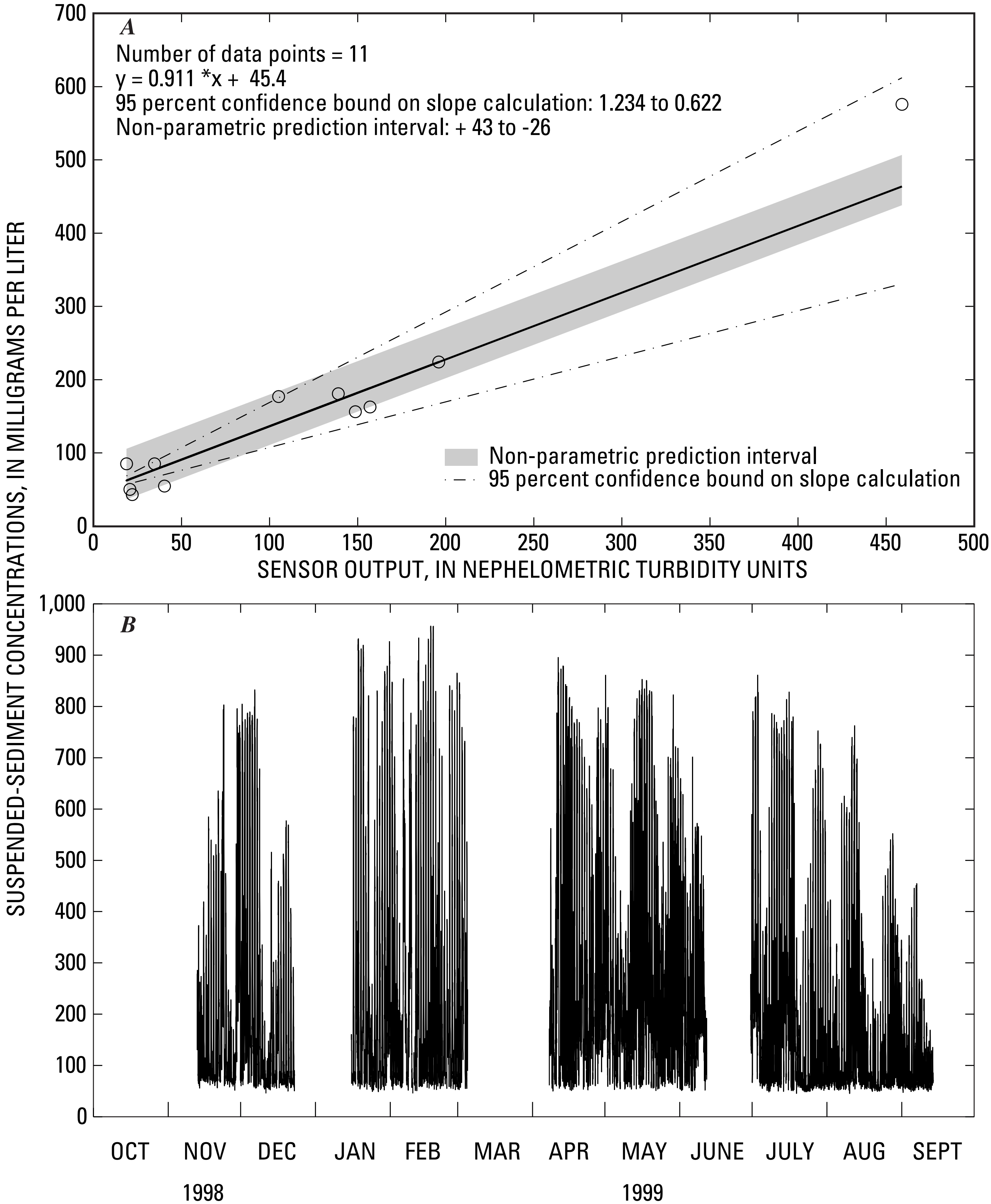


Figure 11. Calibration of near-bottom optical backscatterance sensor (*A*) and near-bottom suspended-sediment concentration (*B*) calculated from sensor readings at Channel Marker 9, San Pablo Bay, California, water year 1999.

Central San Francisco Bay

Point San Pablo

The calibration of the mid-depth sensor was developed using 85 water samples collected from August 15, 1995, through water year 1999 (fig. 12*A*). Shifts to the mid-depth record, calculated from water-sample data not shown on figure 12*A*, were applied from October 5 to November 17, 1998, (–29.5 mV), and September 21 to September 30, 1999, (–42.2 mV), to correct for shifts in sensor output. The calibration of the near-bottom sensor was developed using 108 water samples collected from August 15, 1995, through water year 1999 (fig. 12*B*). A –87 mV shift to the near-bottom record, calculated from water-sample data not shown on figure 12*B*, was applied from July 6 to July 26, 1999, to correct for a shift in sensor output. The data logger malfunctioned from July 26 through September 13, 1999, and data were recorded at 30-minute intervals instead of 15-minute intervals. From mid-July to mid-September 1999, the near-bottom sensor was operating erratically, probably due to a problem with the data logger, and many spikes were edited from the data set. Suspended-sediment concentration data collected during water year 1999 are presented in figure 13 (30-minute data are shown as dots).

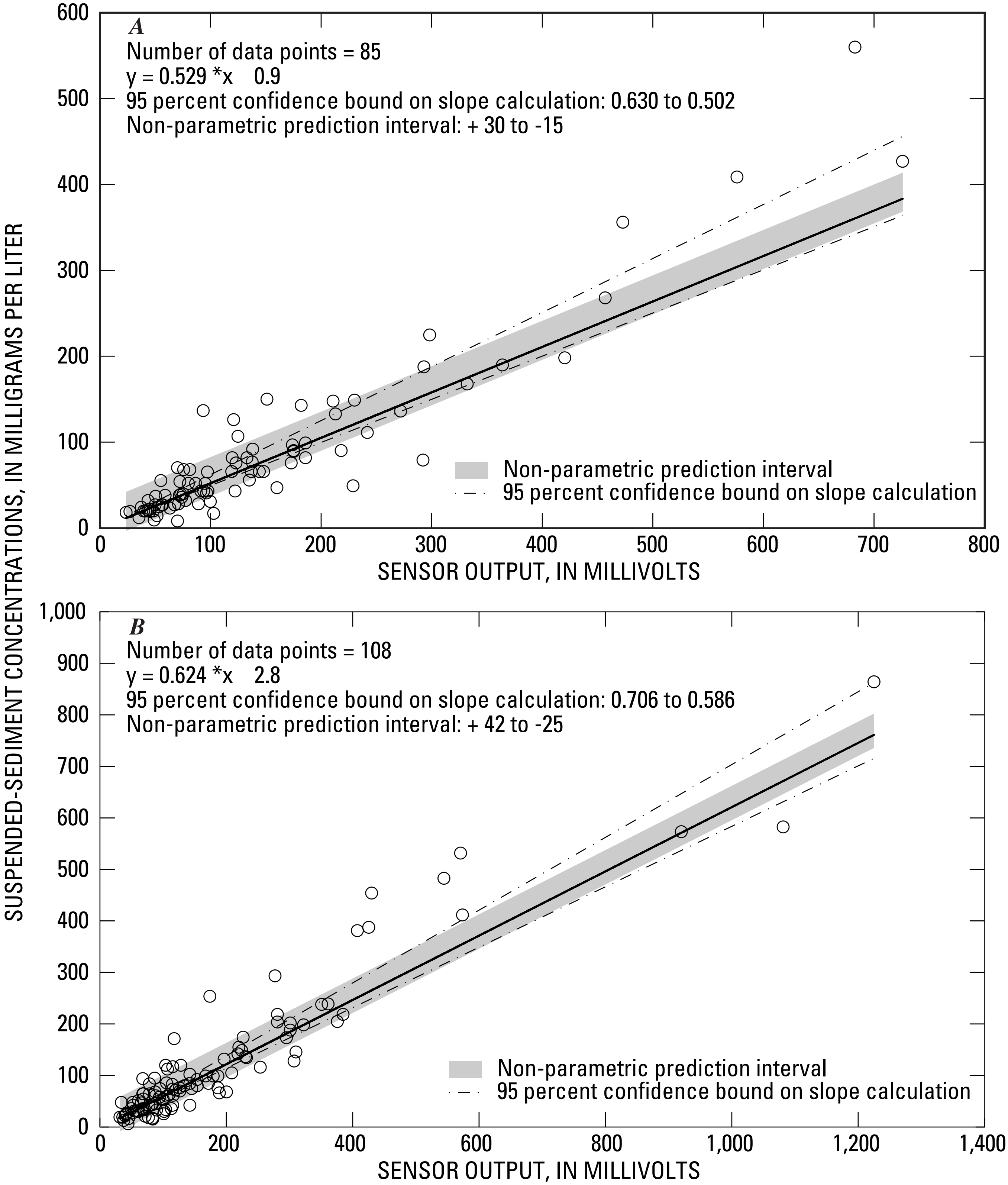


Figure 12. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Point San Pablo, Central San Francisco Bay, California, water year 1999.

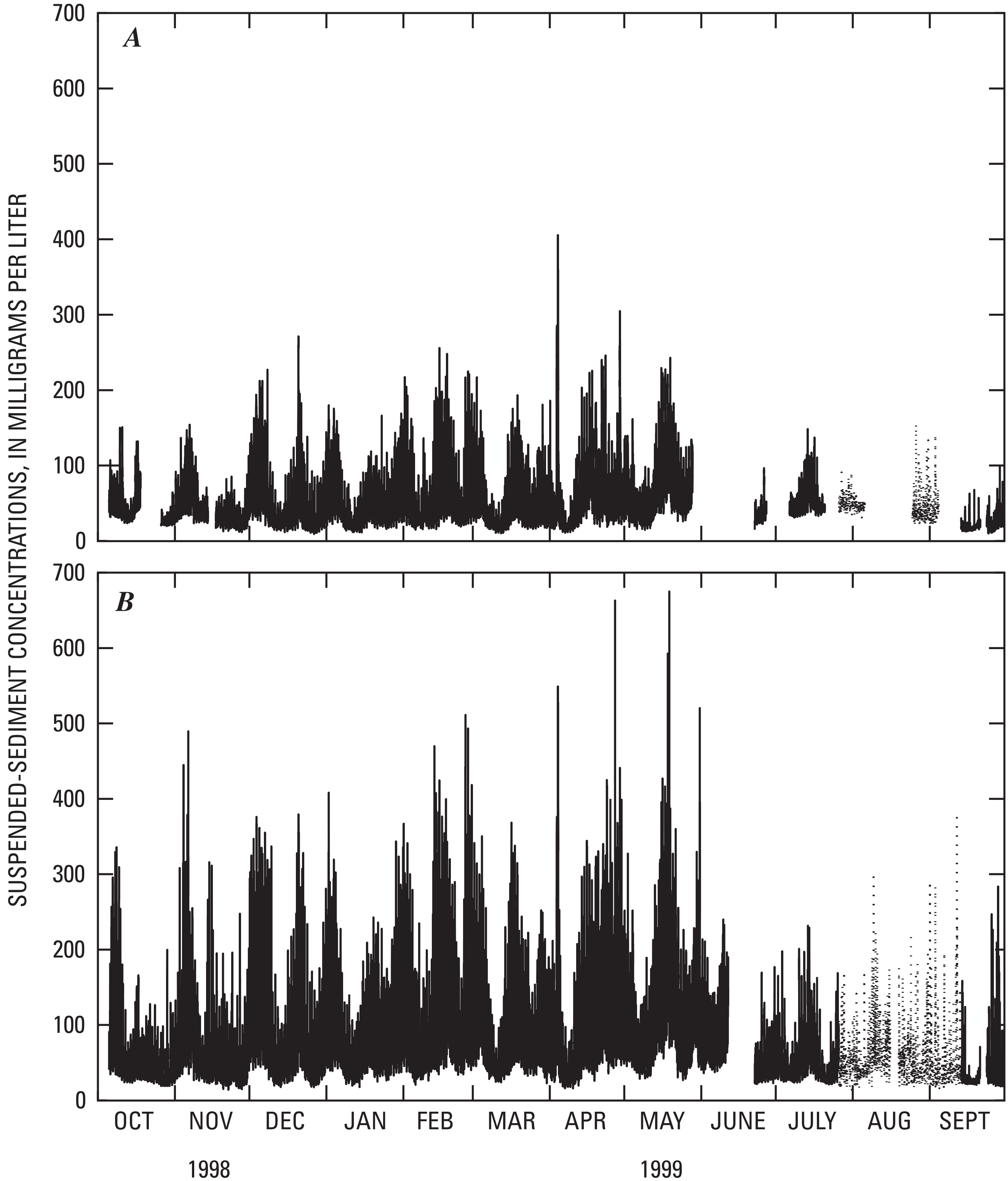


Figure 13. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Point San Pablo, Central San Francisco Bay, California, water year 1999.

Pier 24

The station was shut down due to seismic retrofitting of the bridge from August 14 through October 6, 1998. Calibration of the mid-depth sensor was developed from 20 water samples collected from May 20, 1998, through January 1, 2000 (fig. 14*A*). Calibration of the near-bottom sensor was developed from 77 water samples collected from June 22, 1995, through water year 1999 (fig. 14*B*). Data logger malfunction caused a loss of data from October 15 through November 1, 1998. The station lost power from November 29 through December 16, 1998, and June 7 through June 16, 1999. Suspended-sediment concentration data collected during water year 1999 are presented in figure 15.

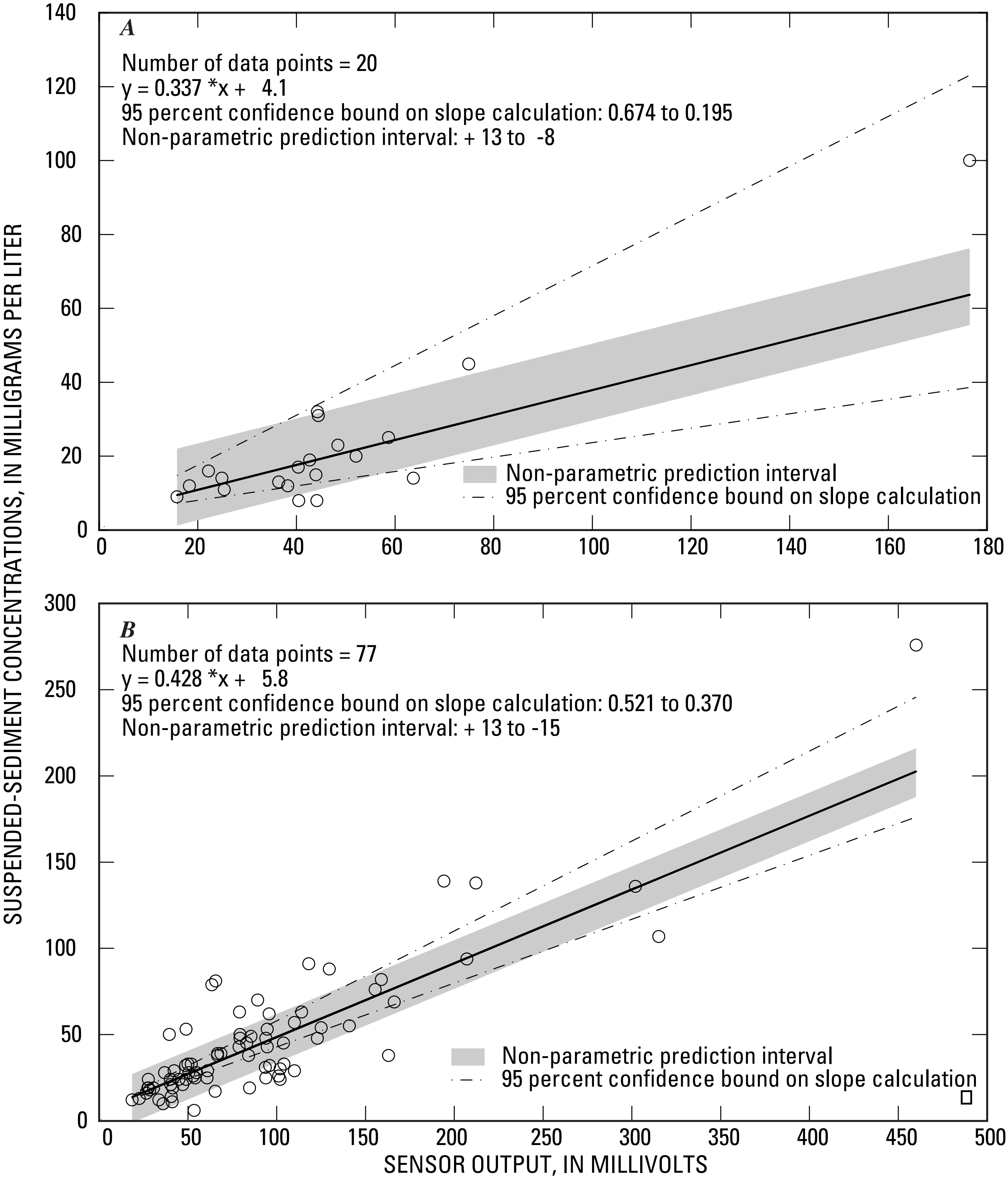


Figure 14. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Pier 24, Central San Francisco Bay, California, water year 1999.

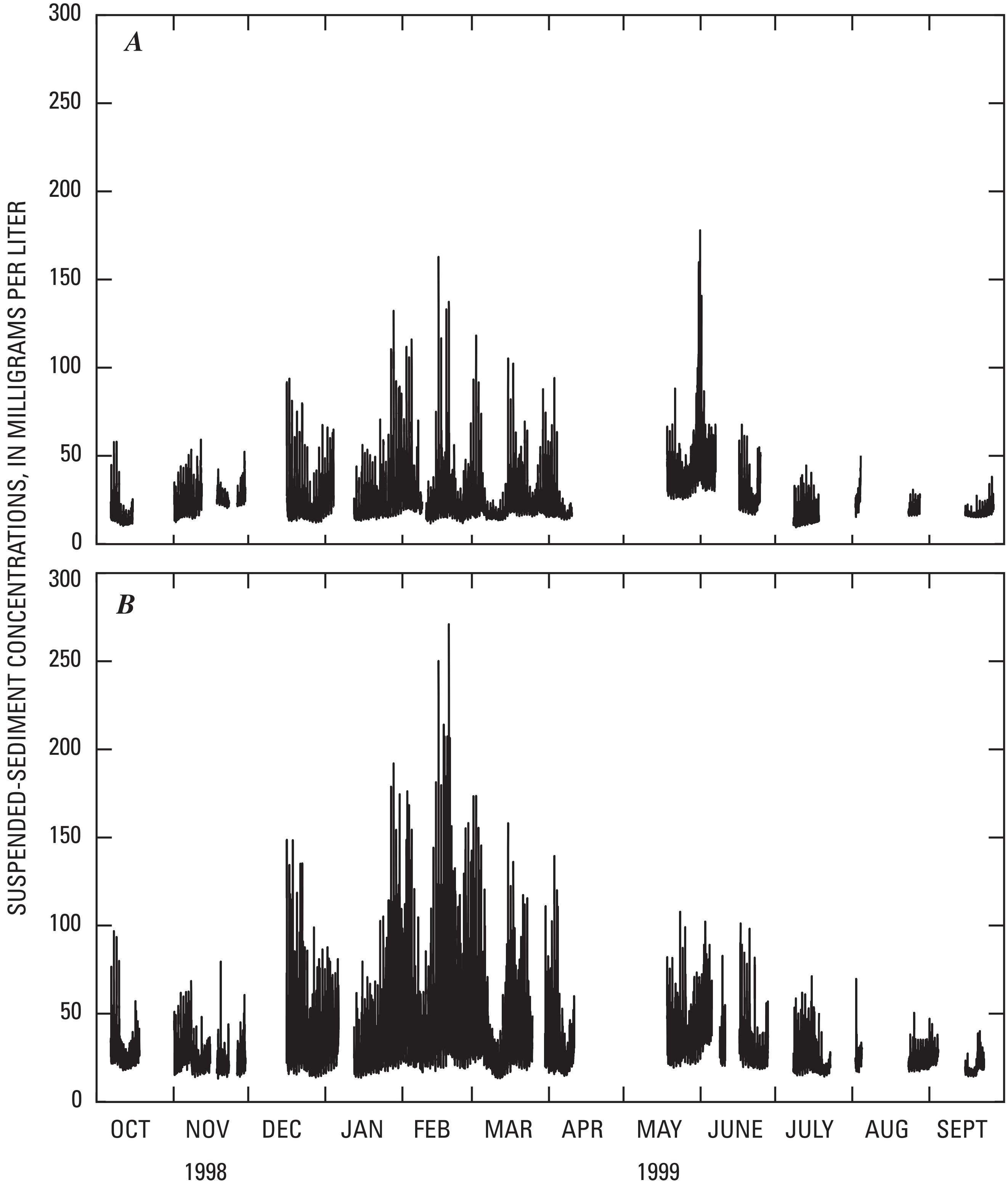


Figure 15. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Pier 24, Central San Francisco Bay, California, water year 1999.

South San Francisco Bay

Channel Marker 17

The calibration of the mid-depth sensor was developed from 47 water samples collected from February 26, 1997, through water year 1999 (fig. 16*A*). The calibration of the near-bottom sensor was developed from 24 water samples collected from July 30, 1998, through water year 1999 (fig. 16*B*). Suspended-sediment concentration data collected during water year 1999 are presented in figure 17.

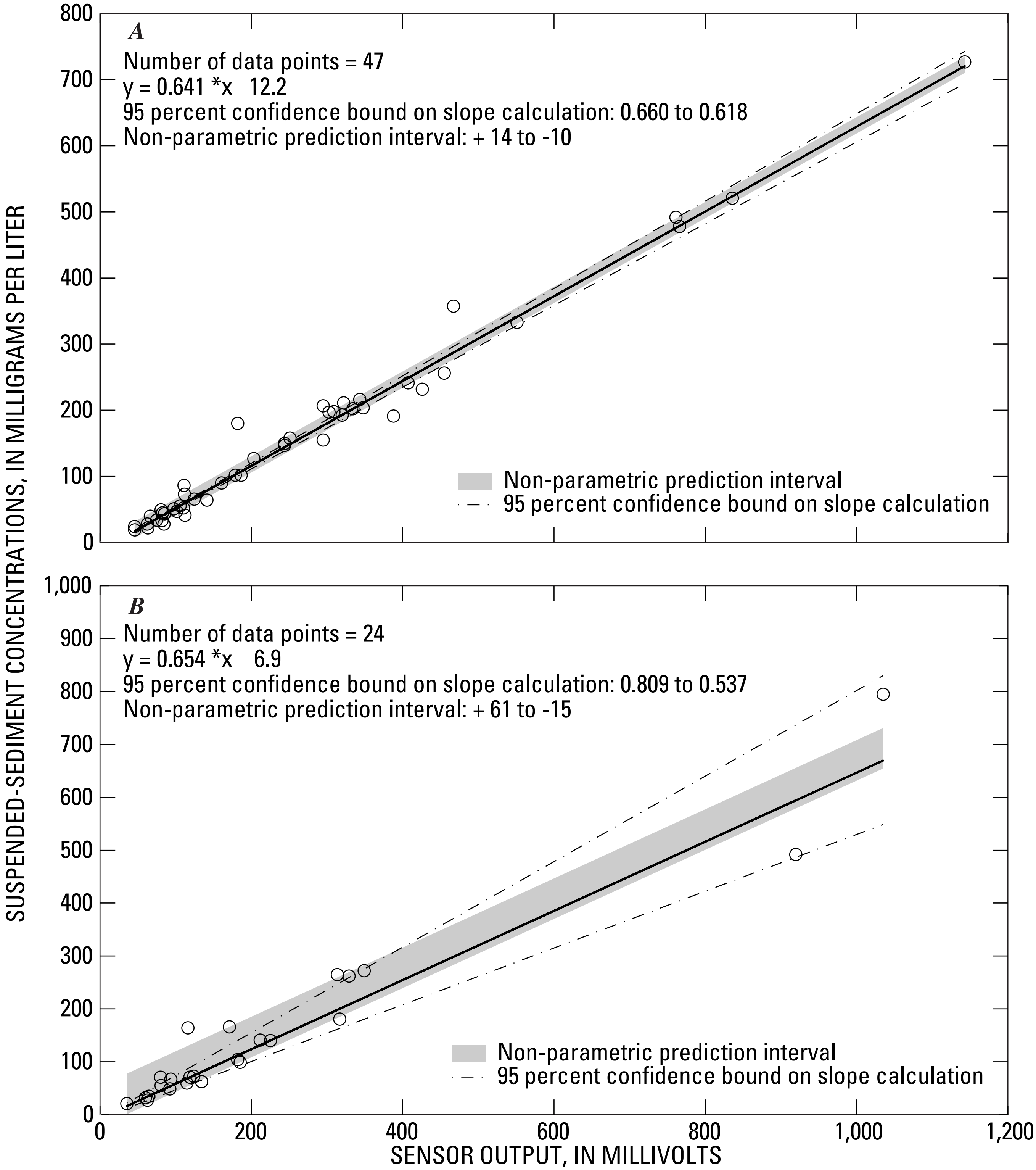


Figure 16. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Channel Marker 17, South San Francisco Bay, California, water year 1999.

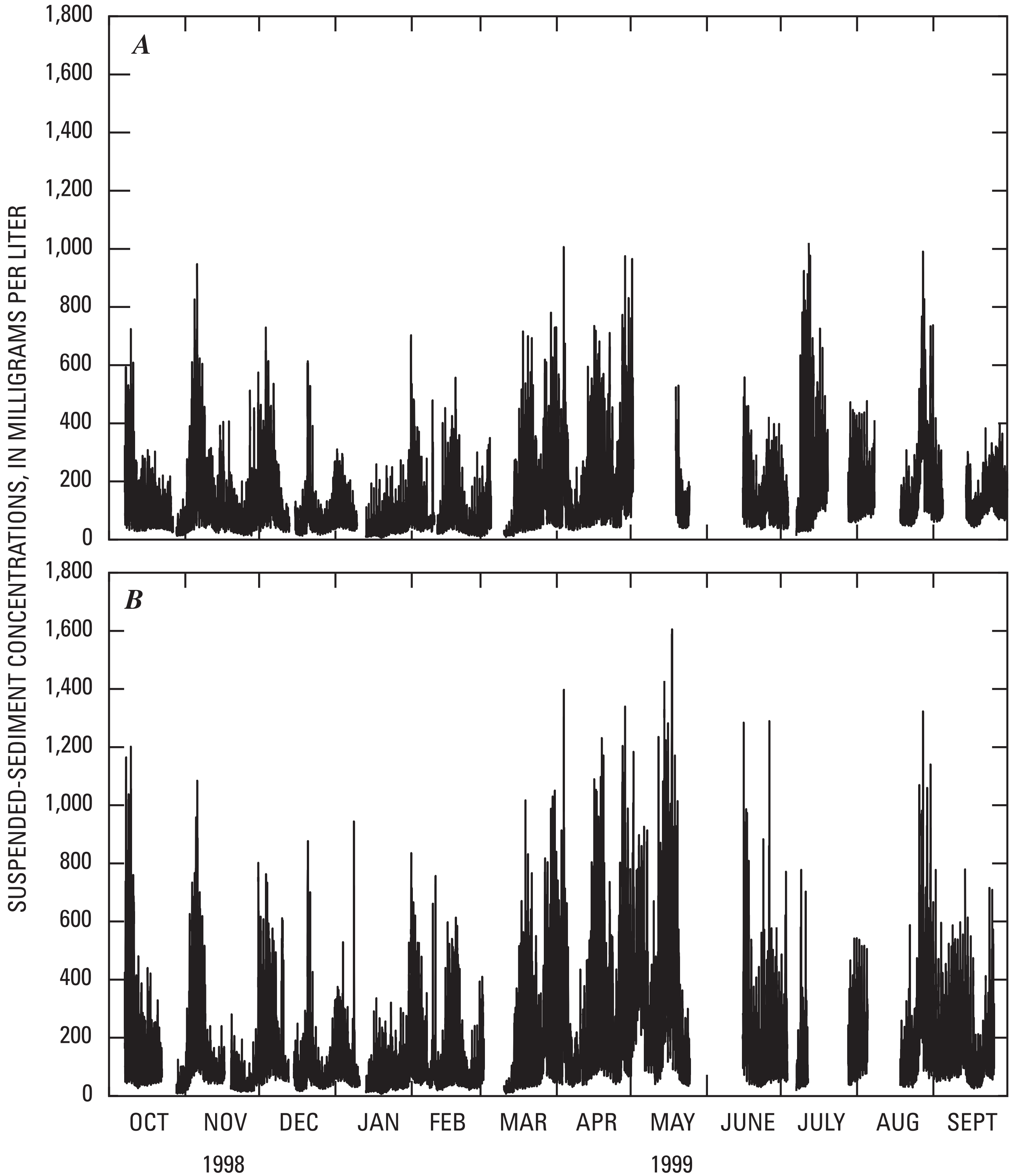


Figure 17. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Channel Marker 17, South San Francisco Bay, California, water year 1999.

Dumbarton Bridge

The calibration of the mid-depth sensor was developed from 81 water samples collected from June 18, 1996, through water year 1999 (fig. 18*A*). A –48.5 mV shift to the record, calculated from water sample data not shown on figure 18*A*, was applied from October 7 through October 28, 1998. The calibration of the near-bottom sensor was developed from 16 water samples collected from October 7, 1998, through water year 1999 (fig. 18*B*). The station lost power from November 19 through December 15, 1998, resulting in a loss of data. Suspended-sediment concentration data collected during water year 1999 are presented in figure 19.

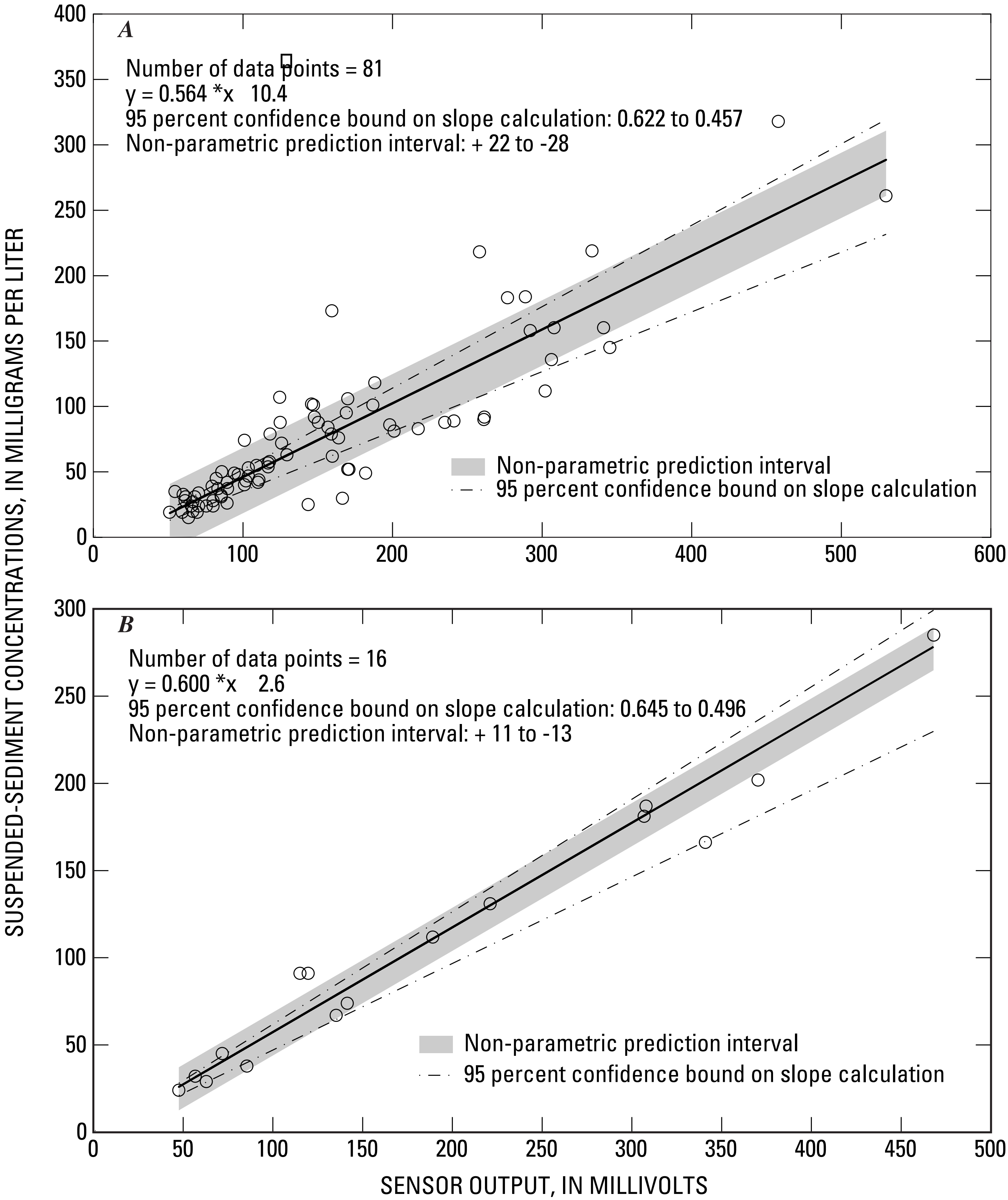


Figure 18. Calibration of mid-depth (*A*) and near-bottom (*B*) optical backscatterance sensors at Dumbarton Bridge, South San Francisco Bay, California, water year 1999.

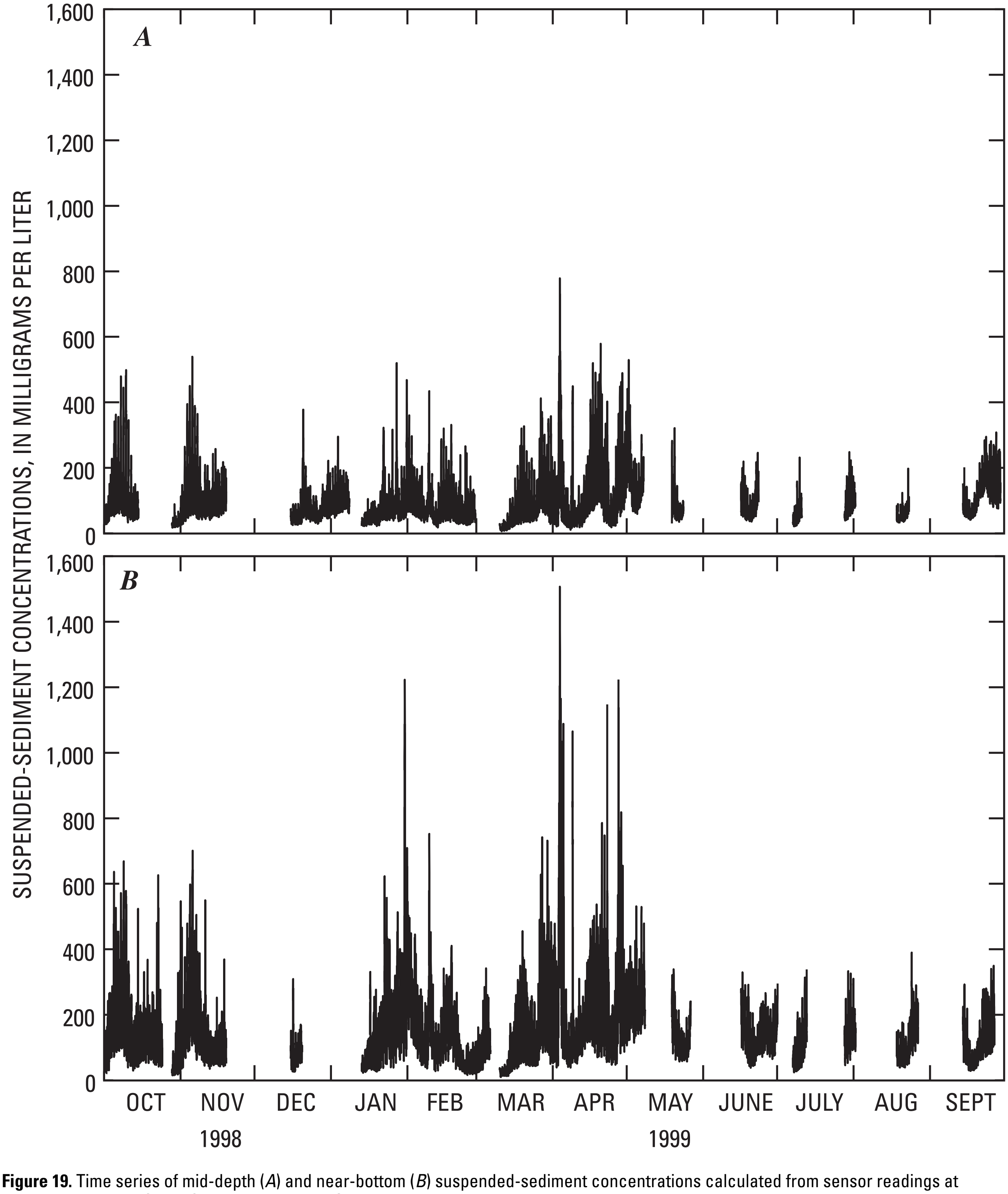


Figure 19. Time series of mid-depth (*A*) and near-bottom (*B*) suspended-sediment concentrations calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 1999.

San Mateo Bridge

The calibration of the mid-depth sensor was developed from 34 water samples collected from March 13, 1997, through January 12, 1999 (fig. 20*A*). There were no valid data collected at the near-bottom depth due to a large mass of biological fouling (hydroids) that had accumulated at the bottom of the suspension cable and interfered with the optical sensor readings. The clump of fouling was removed on January 12, 1999, and data were successfully collected until March 4, 1999, when the station was shut down due to seismic retrofitting of the bridge. Insufficient samples were collected to establish a reliable calibration due to the near-bottom sensor (two samples of low concentration) and the data from January 12 through March 4, 1999, were not used. Suspended-sediment concentration data collected during water year 1999 are presented in figure 20*B*.

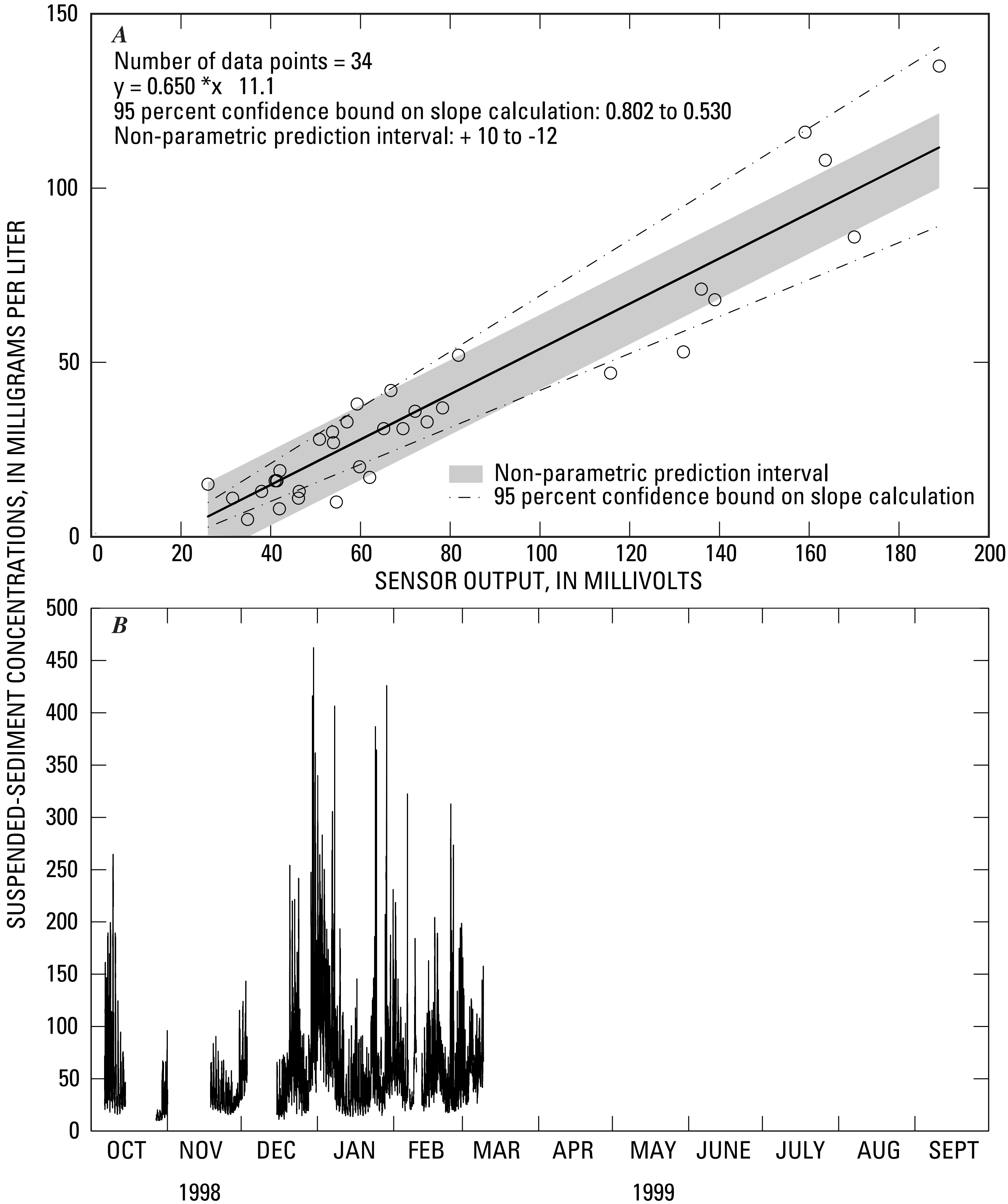


Figure 20. Calibration of mid-depth optical backscatterance sensor (*A*) and mid-depth suspended-sediment concentration (*B*) calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, California, water year 1999.

SUMMARY

Suspended-sediment concentration data were collected by the U.S. Geological Survey (USGS) at one site in Suisun Bay, three sites in San Pablo Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay during water year 1999. Three types of optical backscatterance sensors, controlled by an electronic data logger, were used to monitor suspended sediment. Water samples were collected to calibrate the electrical output of the optical sensors to suspended-sediment concentration, and the recorded data were recovered and edited. Suspended-sediment concentration data are available from the files of the USGS in Sacramento, California.

REFERENCES CITED

Arthur, J.F., and Ball, M.D., 1979, Factors influencing the entrapment of suspended material in the San Francisco Bay–Delta Estuary, *in* Conomos, T.J., (ed.), San Francisco Bay: The urbanized estuary: San Francisco, Pacific Division of the American Association for the Advancement of Science, p. 143–174.

Brown, C.L., and Luoma, S.N., 1995, Use of the euryhaline bivalve *Potamocorbula amurensis* as a biosentinal species to assess trace metal contamination in San Francisco Bay: Marine Ecology Progress Series, v. 124, p. 129–142.

Buchanan, P.A., and Ruhl, C.A., 2000, Summary of suspended-solids concentration data, San Francisco Bays, California, water year 1998: U.S. Geological Survey Open-File Report 00-88, 41 p.

Buchanan, P.A., and Schoellhamer, D.H., 1995, Summary of suspended-solids concentration data, Central and South San Francisco Bays, California, water years 1992 and 1993: U.S. Geological Survey Open-File Report 94-543, 15 p.

———, 1996, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1995: U.S. Geological Survey Open-File Report 96-591, 40 p.

———,1998, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1996: U.S. Geological Survey Open-File Report 98-175, 59 p.

———, 1999, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1997: U.S. Geological Survey Open-File Report 99-189, 52 p.

Buchanan, P.A., Schoellhamer, D.H., and Sheipline, R.C., 1996, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1994: U.S. Geological Survey Open-File Report 95-776, 48 p.

Carlson, P.R., and McCulloch, D.S., 1974, Aerial observations of suspended-sediment plumes in San Francisco Bay and adjacent Pacific Ocean: U.S. Geological Survey Water-Resources Research, v. 2, no. 5, p. 519–526.

Cheng, R.T., and Gartner, J.W., 1984, Tides, tidal and residual currents in San Francisco Bay, California—Results of measurements, 1979–1980:U.S. Geological Survey Water-Resources Investigations Report 84-4339, 72 p.

Cloern, J.E., 1987, Turbidity as a control on phytoplankton biomass and productivity in estuaries: Continental Shelf Research, v. 7, no. 11/12, p. 1367–1381.

———, 1996, Phytoplankton bloom dynamics in coastal ecosystems: a review with some general lessons from sustained investigation of San Francisco Bay, California: Reviews of Geophysics, v. 34, no. 2, p. 127–168.

Cole, B.E., and Cloern, J.E., 1987, An empirical model for estimating phytoplankton productivity in estuaries: Marine Ecology Progress Series, v. 36, p. 299–305.

Conomos, T.J., and Peterson, D.H., 1977, Suspended-particle transport and circulation in San Francisco Bay, an overview: New York, Academic Press. Estuarine Processes, v. 2, p. 82–97.

D & A Instrument Company, 1991, OBS-1 & 3: Suspended sediment and turbidity monitor (rev. 3/91): Port Townsend, WA, D & A Instrument Company Instruction Manual, Part No. OBS-1/3 man, 41 p.

Domagalski, J.L., and Kuivila, K.M., 1993, Distributions of pesticides and organic contaminants between water and suspended sediment, San Francisco Bay, California: Estuaries, v. 16, no. 3A, p. 416–426.

Downing, J.P., 1983, An optical instrument for monitoring suspended particulates in ocean and laboratory: *in* OCEANS 1983, San Francisco, California, August 29–September 1, 1983, Proceedings: p. 199–202.

Downing, J.P., Sternburg, R.W., and Lister, C.R.B., 1981, New instrumentation for the investigation of sediment suspension processes in the shallow marine environment: Marine Geology, v. 42, p. 19–34.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Flegal, A.R., Rivera-Duarte, I., Ritson, P.I., Scelfo, G.M., Smith, G.J., Gordon, M.R., and Sanudo-Wilhelmy, S.A., 1996, Metal contamination in San Francisco Bay waters: Historic perturbations, contemporary concentrations, and future considerations: San Francisco Bay: The Ecosystem, Hollibaugh, J.T. (ed.), Pacific Division of the American Association for the Advancement of Science, San Francisco, p. 173–188.

Gray, J.R., Glysson, G. D., Turcios, L. M., Schwarz, G. E., 2000, Comparability of suspended-sediment concentration and total suspended-solids data: U.S. Geological Survey Water-Resources Investigations Report 00-4191, p. 14.

Hammond, D.E., Fuller, C., Harmon, D., Hartman, B., Korosec, M., Miller, L.G., Rea, R., Warren, S., Berelson, W., and Hager, S.W., 1985, Benthic fluxes in San Francisco Bay: Hydrobiologia, v. 129, p. 69–90.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources—Studies in Environmental Science: Elsevier, New York, v. 49, 522 p.

Jassby, A.D., and Powell, T.M., 1994, Hydrodynamic influences on interannual chlorophyll variability in an estuary: Upper San Francisco Bay–Delta (California, U.S.A.): Estuarine, Coastal and Shelf Science, v. 39, p. 595–618.

Kimmerer, Wim, 1992, An evaluation of existing data in the entrapment zone of the San Francisco Bay Estuary: Tiburon, California, Biosystems Analysis, Inc., Technical Report 33, 49 p.

Kuwabara, J.S., Chang, C.C.Y., Cloern, J.E., Fries, T.L., Davis, J.A., and Luoma, S.N., 1989, Trace metal associations in the water column of South San Francisco Bay, California: Estuarine, Coastal and Shelf Science, v. 28, p. 307–325.

Levesque, V.A., and Schoellhamer, D.H., 1995, Summary of sediment resuspension monitoring, Old Tampa Bay and Hillsborough Bay, Florida, 1988–91: U.S. Geological Survey Water-Resources Investigations Report 94-4081, 31 p.

Luoma, S.N., 1996, The developing framework of marine ecotoxicology: Pollutants as a variable in marine ecosystems?: Journal of experimental marine biology and ecology, v. 200, p. 29–55.

Luoma, S.N., Cain, D., and Johansson, C., 1985, Temporal fluctuations of silver, copper, and zinc in the bivalve *Macoma balthica* at five stations in South San Francisco Bay: Hydrobiologia, v. 129, p. 109–120.

Peterson, D.H., Conomos, T.J., Broenkow, W.W., and Doherty, P.C., 1975, Location of the non-tidal current null zone in northern San Francisco Bay: Estuarine and Coastal Marine Science, v. 3, p. 1–11.

Porterfield, George, 1980, Sediment transport of streams tributary to San Francisco, San Pablo, and Suisun Bays, California, 1909–1966: U.S. Geological Survey Water-Resources Investigations Report 80-64, 91 p.

Powell, T.M., Cloern, J.E., and Huzzey, L.M., 1989, Spatial and temporal variability in South San Francisco Bay (U.S.A.). I. Horizontal distributions of salinity, suspended sediments, and phytoplankton biomass and productivity: Estuarine, Coastal and Shelf Science, v. 28, p. 583–597.

Schoellhamer, D.H., 1996, Factors affecting suspended-sediment concentrations in South San Francisco Bay, California: Journal of Geophysical Research, v. 101, no. C5, p. 12087–12095.

Schoellhamer, D.H., and Burau, J.R., 1998, Summary of findings about circulation and the estuarine turbidity maximum in Suisun Bay, California: U.S. Geological Survey Fact Sheet FS-047-98, 6 p.

Siegel, A.R., 1982, Robust regression using repeated medians: Biometrika, v. ‘69, p. 242–244.

Smith, L.H., 1987, A review of circulation and mixing studies of San Francisco Bay, California: U.S. Geological Survey Circular 1015, 38 p.

U.S. Environmental Protection Agency, 1992, State of the estuary: Dredging and waterway modification: U.S. Environmental Protection Agency San Francisco Estuary Project, chap. 8, p. 191–215.

U.S. Geological Survey, USGS Publications Related to Continuous Monitoring of San Francisco Bay: accessed January 19, 2001, at URL http://ca.water.usgs.gov/abstract/sfbay/sfbaycontbib.html/

USGS science for a changing world

Water Resources of California

USGS Publications Related to Continuous Monitoring of San Francisco Bay

2001

Ruhl, C.A., and Schoellhamer, D.H., 2001, Time series of SSC, salinity, temperature, and total mercury concentration in San Francisco Bay during water year 1998: Regional Monitoring Program for Trace Substances contribution number 44, San Francisco Estuary Institute, Richmond, California. URL http://www.sfei.org/rmp/reports/time_series/timeseries_cont43.pdf (947 KB PDF)

Schoellhamer, D.H., 2001, Continiuous monitoring of suspended sediment in rivers by use of optical sensors: Proceedings of the Seventh Federal Interagency Sedimentation Conference, Reno Nevada, March 25-29, 2001, p. III-160 - III-167. URL: http://ca.water.usgs.gov/abstract/sfbay/Schoellhamer.pdf (293 KB PDF)

Schoellhamer, D.H., 2001, Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay, in McAnally, W.H. and Mehta, A.J., ed., Coastal and Estuarine Fine Sediment Transport Processes: Elsevier Science B.V., p. 343-357. URL: http://ca.water.usgs.gov/abstract/sfbay/elsevier0102.pdf (160 KB PDF)

2000

Brennan, M.L., Monismith, S.G., Schoellhamer, D.H., and Burau, J.R., 2000, Tidal asymmetry of erodibility at a site in San Francisco Bay, USA: Proceedings of the Sixth International Conference on Nearshore and Estuarine Cohesive Sediment Transport Processes, Delft, The Netherlands, September 4-8, 2000, p. 6-7.

Buchanan, P.A., 2000, Specific conductance, water temperature, and water level data from San Francisco Bay, California, in water year 1999: IEP Newsletter, v. 13, no. 3, p. 17-20. URL http://www.iep.ca.gov/report/newsletter/2000summer/

Buchanan, P.A., and Ruhl, C.A., 2000, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1998: U.S. Geological Survey Open File Report 00-88, 41 p.

Moon, G.E., Kuivila, K., Ruhl, C., and Schoellhamer, D., 2000, Exposure of Delta Smelt to dissolved pesticides in 1998 and 1999: Interagency Ecological Program Newsletter, v. 13, no. 4, p. 27-33.

Ruhl, C.A., and Schoellhamer, D.H., Spatial and seasonal variability of suspended-sediment concentrations in Honker Bay, a shallow subembayment of San Francisco Bay: Proceedings of the CALFED Science Conference, Sacramento, California, October 3-5, 2000, p. 218.

Schoellhamer, D.H., Burau, J.R., Brennan, M.L., and Monismith, S.G., 2000, Transfer of cohesive sediment between the bed and water column at a site in San Francisco Bay, USA: Proceedings of the Sixth International Conference on Nearshore and Estuarine Cohesive Sediment Transport Processes, Delft, The Netherlands, September 4-8, 2000, p. 8-9.

Schoellhamer, D.H., and Dinehart, R.L., 2000, Suspended-sediment supply to the Delta from the Sacramento River: Proceedings of the CALFED Science Conference, Sacramento, California, October 3-5, 2000, p. 124. URL http://ca.water.usgs.gov/program/sfbay/calfedsed/SedimentSupply.html

Takekawa, J.Y., Martinelli, G.M., Miles, A.K., Fregien, S., Schoellhamer, D.H., Duffy, W.G., and Saiki, M.K., 2000, Salt ponds and avian communities: Will benefits of tidal wetland restoration exceed costs to waterbirds?: Proceedings of the CALFED Science Conference, Sacramento, California, October 3-5, 2000, p. 135.

Warner, J.C., Schoellhamer, D.H., Burau, J.R., and Schladow, S.G., 2000, Effects of Tidal Current Phase at the Junction of Two Straits: Proceedings of the Fall meeting of the American Geophysical Union, San Francisco, California, December 15-19, 2000. AGU Citation

1999

Buchanan, P.A., 1999, Specific conductance, water temperature, and water level data, San Francisco Bay, California, water year 1998: Interagency Ecological Program Newsletter (PDF), v. 12, no. 4, p. 46-51.

Buchanan, P.A., and Schoellhamer, D.H., 1999, Summary of suspended-solids concentration data in San Francisco Bay, California, water year 1997: U.S. Geological Survey Open File Report 99-189, 52 p. URL http://ca.water.usgs.gov/rep/ofr99189/

Dinehart, R.L., and Schoellhamer, D.H., 1999, Sedimentation in the Delta of the Sacramento and San Joaquin Rivers: Proceedings of the 4th biennial State of the Estuary Conference, San Francisco, Calif., March 17-19, 1999, p. 75.

Friebel, M.F., Freeman, L.A., Webster, M.D., and Anderson, S.W., 1999, Water resources data, California, water year 1998: U.S. Geological Survey Wataer-Data Report CA-98-2, v. 2, 360 p. URL http://ca.water.usgs.gov/data/

Oltmann, R.N., Schoellhamer, D.H., and Dinehart, R.L., 1999, Sediment inflow to the Sacramento-San Joaquin Delta and the San Francisco Bay: Interagency Ecological Program newsletter, v. 12, no. 1, pp. 30-33.

Ruhl, C.A., and Schoellhamer, D.H., 1999, Time series of suspended-solids concentration in Honker Bay during water year 1997: 1997 Annual Report of the Regional Monitoring Program for Trace Substances, p. 82-92, URL http://www.sfei.org/rmp/1997/c0304.htm

Ruhl, C.A., Schoellhamer, D.H., Stumpf, R.P., and Lindsay, C.L., 1999, Remote sensing: Visual cues to suspended-solids transport in San Francisco Bay, California: Proceedings of the 4th biennial State of the Estuary Conference, San Francisco, Calif., March 17-19, 1999, p. 74.

Warner, J.C., Schladow, S.G., and Schoellhamer, D.H., 1999, Summary and analysis, hydrodynamic and water-quality data for the Napa/Sonoma Marsh complex, Final Report: University of California, Davis, Department of Civil and Environmental Engineering.

Warner, J.C., Schoellhamer, D.H., Schladow, S.G., and Burau, J.R., 1999, Napa/Sonoma Marsh Hydrodynamic and Water-Quality Study: Proceedings of the 4th biennial State of the Estuary Conference, San Francisco, Calif., March 17-19, 1999, p. 126.

1998

Buchanan, P.A., and Schoellhamer, D.H., 1998, Summary of suspended-solids concentration data in San Francisco Bay, California, water year 1996: U.S. Geological Survey Open File Report 98-175, 59 p.

Schoellhamer, D.H., 1998, The weak influence of flocculation at low salinities on the distribution of suspended-solids concentration in the San Francisco Bay estuary, California, USA: Proceedings of the Fifth International Conference on Cohesive Sediment Transport, Seoul, Korea, May 25-29, 1998, p. 1.

Schoellhamer, D.H., and Buchanan, P.A., 1998, Measuring suspended-solids concentration with optical backscatterance sensors: Proceedings of the Federal Interagency Workshop on Sediment Transport Technology for the 21st Century, St. Petersburg, Florida, February 17-19, 1998, URL http://water.usgs.gov/osw/techniques/sedtech21/schoellhamer.html

Schoellhamer, D.H., and Burau, J.R., 1998, Summary of findings about circulation and the estuarine turbidity maximum in Suisun Bay, California, U.S. Geological Survey Fact Sheet FS-047-98, 6 p. URL: http://sfbay.wr.usgs.gov/access/suisunbay/dschoell/

Schoellhamer, D.H., Cacchione, D.A., Rubin, D.M., Cheng, R.T., Dingler, J.R., Jaffe, B.E., and Stumpf, R.P., 1997, Sediment-Transport Research in San Francisco Bay: Proceedings of USGS Sediment

Workshop, Harpers Ferry, West Virginia, February 4-7, 1997, URL
http://wwwrvares.er.usgs.gov/osw/workshop/schoellhamer.html

Webster, M.D., Friebel, M.F., and Freeman, L.A., 1998, Water resources data, California, water year 1997: U.S. Geological Survey Water-Data Report CA-97-2, v. 2, 322 p.

1997

Freeman, L.A., Webster, M.D., and Friebel, M.F., 1997, Water resources data, California, water year 1996: U.S. Geological Survey Water-Data Report CA-96-2, v. 2, 356 p.

Jennings, B., Schoellhamer, D.H., and Kuivila, K.M., 1997, Optimum sampling strategy for sediment-associated pesticides in Suisun Bay: Interagency Ecological Program newsletter, v. 10, no. 4, p. 16-20.

Schoellhamer, D.H., 1997, Time Series of Trace Element Concentrations Calculated from Time Series of Suspended-Solids Concentrations and RMP Water Samples: 1995 Annual Report of the Regional Monitoring Program for Trace Substances, p. 53-55.

Schoellhamer, D.H., 1997, Time series of SSC, salinity, temperature, and total mercury concentration in San Francisco Bay during water year 1996: 1996 Annual Report of the Regional Monitoring Program for Trace Substances, p. 65-77.

Schoellhamer, D.H., Cacchione, D.A., Rubin, D.M., Cheng, R.T., Dingler, J.R., Jaffe, B.E., and Stumpf, R.P., 1997, Sediment-Transport Research in San Francisco Bay: Proceedings of USGS Sediment Workshop, Harpers Ferry, West Virginia, February 4-7, 1997. URL:
http://water.usgs.gov/osw/techniques/workshop/schoellhamer.html

Warner, J.C., Schoellhamer, D.H., and Burau, J.R., 1997, A sediment transport pathway in the back of a nearly semienclosed subembayment of San Francisco Bay, California: Proceedings of the XXVII International Association of Hydraulic Research Congress, August 10-15, 1997, San Francisco, California, v. 2, p. 1096-1101.

1996

Buchanan, P.A., and Schoellhamer, D.H., 1996, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1995: U.S. Geological Survey Open-File Report 96-591, 40 p.

Buchanan, P.A., Schoellhamer, D.H., and Sheipline, R.C., 1996, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1994: U.S. Geological Survey Open-File Report 95-776, 48 p.

Burau, J.R., and Schoellhamer, D.H., 1996, Residual Transport in Suisun Cutoff, San Francisco Bay,

California, During Summer 1995: Part 1, Salt Transport: abstract for the 1996 Fall AGU meeting, San Francisco, California, December 15-19, 1996.

Friebel, M. F., Trujillo, L. F., and Markham, K. L., 1996, Water resources data, California, water year 1995, vol. 2, Pacific slope basins from Arroyo Grande to Oregon state line except Central Valley: U.S. Geological Survey Water-Data Report CA-95-2, 339 pp.

Lacy, J.R., Schoellhamer, D.H., and Burau, J.R., 1996, Suspended-solids flux at a shallow-water site in South San Francisco Bay, California: Proceedings of the North American Water and Environment Congress, Anaheim, California, June 24-28, 1996.

Schoellhamer, D.H., 1996, Central San Francisco Bay suspended-sediment transport processes and comparison of continuous and discrete measurements of suspended-solids concentrations: San Francisco Estuary Regional Monitoring Program for Trace Substances, 1994 Annual Report, p. 198-206.

Schoellhamer, D.H., 1996, Factors affecting suspended-solids concentrations in South San Francisco Bay, California: Journal of Geophysical Research, v. 101, no. C5, p. 12087-12095.

Schoellhamer, D.H., 1996, Suspended-solids concentrations in San Francisco Bay, California: Proceedings of the Third Biennial State of the Estuary Conference, San Francisco, California, October 10-12, 1996, p. 54.

Schoellhamer, D.H., and Burau, J.R., 1996, Residual Transport in Suisun Cutoff, San Francisco Bay, California, During Summer 1995: Part 2, Sediment Transport: abstract for the 1996 Fall AGU meeting, San Francisco, California, December 15-19, 1996.

Schoellhamer, D.H., Oltmann, R.N., Jaffe, B.E., and Smith, R.E., 1996, Sediment supply and wetlands in San Francisco Bay: Proceedings of the Third Biennial State of the Estuary Conference, San Francisco, California, October 10-12, 1996. p. 23.

1995

Ayers, W., and others, 1995, Water resources data, California, water year 1994, vol. 2, Pacific slope basins from Arroyo Grande to Oregon state line except Central Valley: U.S. Geological Survey Water-Data Report CA-94-2, 357 pp.

Buchanan, P.A., and Schoellhamer, D.H., 1995, Summary of suspended-solids concentration data, Central and South San Francisco Bays, California, water years 1992 and 1993: U.S. Geological Survey Open-File Report 94-543, 15 p.

Tobin, A., Schoellhamer, D.H., and Burau, J.R., 1995, Suspended-solids flux in Suisun Bay, California: Proceedings of the First International Conference on Water Resources Engineering, San Antonio, Texas,

August 14-18, 1995, v. 2, p. 1511-1515.

1994

Palmer, J. R., Friebel, M. F., Trujillo, L. F., and Markham, K. L., 1994, Water resources data, California, water year 1993, vol. 2, Pacific slope basins from Arroyo Grande to Oregon state line except Central Valley: U.S. Geological Survey Water-Data Report CA-93-2, 412 pp.

Schoellhamer, D.H., 1994, Central San Francisco Bay suspended-sediment processes study and comparison of continuous and discrete measurements of suspended-solids concentrations: San Francisco Estuary Regional Monitoring Program for Trace Substances, 1993 Annual Report, p. 129-134.

Schoellhamer, D.H., 1994, Suspended-solids concentrations in central San Francisco Bay during 1993 winter runoff: Eos, v. 75, no. 3, p. 122. (1994 AGU Ocean Sciences meeting, San Diego, California)

1993

Markham, K. L., Palmer, J. R., Friebel, M. F., and Trujillo, L. F., 1993, Water resources data, California, water year 1992, vol. 2, Pacific slope basins from Arroyo Grande to Oregon state line except Central Valley: U.S. Geological Survey Water-Data Report CA-92-2, 405 pp.

1992

Trujillo, L.F., Markham, K.L., Palmer, J.R., and Friebel, M.F., 1992, Water resources data--California, water year 1991. Volume 2, Pacific slope basins from Arroyo Grande to Oregon State line except Central Valley: U.S. Geological Survey Water-Data Report CA-91-2, 336 p.

1991

Shelton, W.F., Trujillo, L.F., Markham, K.L., and Palmer, J.R., 1991, Water resources data--California, water year 1990. Volume 2. Pacific slope basins from Arroyo Grande to Oregon State line except Central Valley: U.S. Geological Survey Water-Data Report CA-90-2, 333 p.

URL: http://ca.water.usgs.gov/abstract/sfbay/sfbaycontbib.html
Contact: David H. Schoellhamer
Maintained: webmaster@maildcascr.wr.usgs.gov
Last modified: Wed Jul 11 09:45:05 2001

CALFED BAY-DELTA PROGRAM

ABOUT CALFED
WHAT'S NEW
PROGRAMS
REPORTS & STUDIES
CALENDAR
ENVIRONMENTAL DOCUMENTATION
ARCHIVES
CONTACT INFO
RELATED WEBSITES
REQUEST FOR PROPOSALS
POLICY GROUP
JOB OPPORTUNITIES UPDATED

[About CALFED | Policy Group | Programs | Reports Studies |

Calendar | Environmental Documentation | Archives | Policy Group| Related Websites |

Contact Information | Request for Proposals | Job Opportunities | Programmatic Record of Decision]

Disclaimer

Please direct comments or suggestions concerning information on
the CALFED Bay-Delta Program Website to:

CALFED Bay-Delta Program
1416 9th Street, Room 1155
Sacramento, CA 95814
(916) 657-2666

Margaret Gidding
(916) 654-7137
gidding@water.ca.gov

For technical comments:

Polly Petersen
(916) 657-4941
pollyp@water.ca.gov

CALIFORNIA THE GOLDEN STATE

GOVERNOR'S HOMEPAGE

Quick Menu

"Our mission is to preserve and enhance the quality of California's water resources and ensure the proper allocation and efficient use for the benefit of present and future generations."

1515 Clay St. Suite 1400
Oakland, CA 94612
Phone # (510)622-2300
Fax # (510)622-2460

We are part of
California Enviromental Protection Agency

Our new e-mail subscription to the monthly agenda is here. Click to subscribe.

EPA Customer Survey

Search

+url:www.swrcb.ca.gov/rw

Go

Note: Leave the +url:www.swrcb.ca.gov/rwqcb2 in order to search the region 2 website only.

Last Updated
Thursday, August 16, 2001

News Items

CALIFORNIA'S ENERGY CHALLENGE

Notice: The next Board Meeting is September 19, 2001.

Impaired Water Bodies 303(d) List and TMDLs

Notice of Public Hearing , Notice of Filing a Draft Environmental Document in the Matter of Proposed Amendments to the Water Quality Control Plan for the San Francisco Bay Basin

Proposition 13

More News Items

Items for Comments

Draft Guidelines for the Beneficial Use of Dredged Materials

Application of Risk-Based Screening Levels and Decision Making to Sites With Impacted Soil and Groundwater (Interim Final - August 2000)

Pending Enforcement Actions

Tentative Orders for Public Comment

Ombudsman/Small Business Liaison

Site Map Any comments or suggestions can be directed to webmaster2@rb2.swrcb.ca.gov

Welcome to the US Army Corps of Engineers
San Francisco District
News Organization Site Index

Archaeology
District Information
DMMO
Doing Business with Us
Employment Opportunities
Projects
Publications and Studies
Recreation
Regulatory / Permits
Special Programs and Capabilities
What's New

Humboldt Harbor

USACE Home
Div Dist Ctr Lab FOA
You Are Here

The POC for this page:
Frank Conway,CESPN-IM-I
415-977-8601
San Francisco, CA 94105-2197

Webmaster@spd.usace.army.mil
Last updated June 21, 2001

News | Organization | Site Index
Archaeology | District Information | DMMO | Doing Business With Us | Employment Opportunities | Projects
Publications and Studies | Recreation | Regulatory/Permits | Special Programs and Capabilities | What's New

USACE Home | South Pacific Division